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A SYSTEMS PERSPECTIVE ON PRODUCTION-QUALITY-SALES INTERFACE

A THESIS

Presented to

The Faculty of the Graduate Division

by

John E. Knight, Jr.

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A SYSTEMS PERSPECTIVE ON PRODUCTION-QUALITY-SALES INTERFACE

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SUMMARY

A study on some of the controlling interactions in the production-quality-sales system has been conducted to gain insight into the complex company-market environment. The purpose of the study was to attempt to explain cyclic swings in production rates in technically oriented companies through the understanding of the important variables which give the system its dynamic behavior.

An industrial dynamics model of the controlling variables and feedback loops was hypothesized. Included in these variables were management reactions to various pressures created by the system. Thus the model contains not only variables relating to physical plant capacity, market size, and work force, but also management decisions on overtime determination, hiring and firing workers, and allocation of sales effort between sales and service. The behavior of each of these factors in relationship to other factors determines the patterns of dynamic behavior experienced in the system.

The production-quality-sales model pointed out some interesting results. It was found that the sales force and its balancing decision created much system instability. Also it was found that the control of the positive feedback loop in the model was the main consideration in gaining final system stability. Unfortunately, a few variables in the system allowed this loop to have dominance and cause violent oscillatory behavior and sometimes explosive oscillatory behavior.

The model points to the need for overall system planning,

organizing, and controlling in order to mesh diverse sections of business into a highly coordinated and stable business.

CHAPTER I

INTRODUCTION

Seasonal or cyclic patterns of business have constantly received considerable management thought and effort over the years. To the operating manager, these cycles cause great consternation and dramatize management's relative inability to maintain effective control of their business. Admittedly, much of the random and cyclic pattern of business is clearly beyond the direct control of the operating manager of an individual industrial firm. However, many of the policies, decisions, and reactions to pressures made by managers can also result in cyclic patterns of business within the company even though no such phenomenon exists in the market.

In order to cope with such uncertainties and instability in business, management has introduced many buffer-type mechanisms to reduce the impact of these seemingly uncontrollable and costly fluctuations. Thus, inventories are intended to minimize the necessity of exactly equating production and sales. Order backlogs accumulate, providing the company with a margin of security against random and cyclic demand and order placement. These examples and others show management's concern over instability of all phases of their business, and their efforts to combat such problems.

Each of these buffer mechanisms when viewed independently seems to logically provide the necessary control to stabilize the desired variable of importance. However, the sum of the stabilized parts fails to necessarily insure stability of the whole. Many businesses still continue to experience seemingly unexplainable cyclical fluctuations even though control and buffer mechanisms exist.

Such precautions and safeguards as inventory, quality control systems, sales quotas, and backlog have often been implemented independently of each other. The importance of managerial reactions relating the various areas together, both within the firm and also the interface between the firm and its market, has been neglected. For example, management's reaction to severity of production and backlog crises can create quality characteristics which influence either efficiency or absolute magnitude of sales effort. Changes in sales effort allocation will be reflected in changes in order rates which affect backlog. Therefore, management response to situations in the firm can ultimately affect customer's response to various characteristics of the product through the sales force.

The problem perplexing managers of many technical sales oriented firms centers around fluctuating order rates and production rates. Since no apparent seasonal demand exists for the products, such cyclic behavior must be created within the framework of the firm and its market. Often only one factor will be the main determinant of whether a sales is made or not. That is,probably only one feature of the product actually differentiates and controls the dynamics of one firm's products at the expense of another firm's products. Three general characteristics often regulating the sales of products are delivery delay, price, and quality. The possible consequences of sensitivity to any of these factors can be enormous. Since many technically oriented companies stress quality, the various policies, pressures, and decisions determining a company's concern for maintaining this reputation can create many dynamic reactions both in the firm and in the market via the sales force. Delivery delay and price also create other management decisions instrumental in causing dynamic behavior of the firm, but these reactions will not be deemed as the controlling features of sales in this study. Therefore the study will focus attention on the relationships which can create fluctuating production and sales rates because of managerial policies which relate production, quality, and sales. For example, in the firm overtime can be markedly increased resulting in increased production but decreased quality. In the market where the sales force is allocating its effort between order generation and service repair, slight changes in quality can result in various patterns of sales, dependent on how the salesmen adjust their effort between sales and repairs. The considerations necessary to control such undesirable behavior will be examined in order to gain insight into the complex system behavior.

Problems of examining and controlling these large complex problems suggest a high level systems approach. Such an approach should include all those factors which are significant in producing the observed behavior of the system. These important factors include the organizational structure of flows of information, materials, orders, and effort as well as various delays and management policies which can amplify certain aspects of system behavior. The coordination and control of these inter-departmental activities, in order to be successful, must be done at the highest level of management. Only there can the company decisions and responses to pressures to regulated effectively, and only at top management does the authority and responsibility exist for the exercise of such policy making control.

Since analysis and experimentation of such complex systems would be impossible in real life, use of mathematical model to simulate dynamic business activities will be hypothesized and analyzed. Therefore many variations and different ideas for causes of dynamic systems behavior in the production-quality-sales interface can be explored both inexpensively and rewardingly.

Two main purposes exist for work in this area. First, information regarding the importance of the sales effort balancing decision in the market and its effect on production in the plant needs to be investigated to find those important variables which control system behavior under various model conditions. Secondly, the study hopes to shed additional insight into the complex systems nature relating the firm and market. Further understanding of the controlling variables should lead to management improvement in this area since some of the complexities of the system will be explicitly defined and analyzed.

CHAPTER II

LITERATURE SURVEY

A review of the literature reveals that most past studies in the fields of sales and production have neglected the dynamic systems interrelationships existing between the areas. Rather the literature tends to view problems from an increasingly microscopic view, especially quantitatively. Much work in the area of operations research is aimed in this direction.

Opposing this dominant microscopic trend is the viewpoint of industrial dynamics. By taking a macroscopic view of the business function and using a relatively simple simulation technique, industrial dynamics has concentrated on synthesizing and analyzing complex, dynamic systems. Using the literature from these various areas will provide the necessary background for the comprehensive analysis of the production-quality-sales interface from a broad systems approach.

Pertinent work in the areas of sales and sales effort allocation, production, and industrial dynamics will be discussed briefly to familiarize the reader with recent attempts to describe the areas.

Sales and Sales Effort Allocation

The marketing and sale of the product constitutes one of the most important phases of any business activity. Although many books and articles have been devoted to the topic, the information usually becomes so broad through qualitative generalizations or so narrow through simplifying assumptions, that little intuitive understanding of the systems aspects of sales and sales effort allocation processes is garnered. The studies published deal with sub-topics of more complex systems problems. The range of research in these sub-topics stretches from Mandel's (4) discussion of the qualitative characteristics necessary for successful salesmanship to such mathematical operations research studies done by authors such as Thompson and McNeal (9), Green and Galbert and Robinson (1), and Schussel (7). Each author fails to discuss and analyze the systems aspects of sales as they relate to actual plant production. Omitting such an important consideration fails to solve the problem associated with fluctuations in production, quality, and sales caused by management policy-making structure in each area.

Production in a Systems Structure

Since the majority of the literature on production problems either quantifies or optimizes time independent problems or discusses qualitative aspects of production, a prolonged discussion of its relevance to a dynamic simulation model would be inappropriate. Rather, time dependent simulation studies illustrating the systems nature of production, selling, ordering and quality will be reviewed.

Many of the interactions within the production system are examined in the book Industrial Dynamics (2) by Jay W. Forrester. Forrester's text deals extensively with the control systems nature of business activity, especially in the production sector. Other studies and articles of interest include Nord's examination of the Precision Company (5) and its problem of work-load fluctuation. Nord's work concentrates on the controlling effect delivery delay has on the Precision Company dynamics.

Acceptable quality is in itself a dynamic consideration when placed within a systems framework. Roberts (6) insists that given a constant quality, fluctuating rejection rates can occur when human testing and judgement is used. Additional work on the relationship of productivity and overtime considerations on quality (10) also provided information concerning the problem previously described.

The Modeling Philosophy

The basic research and development of the modeling philosophy industrial dynamics was begun at Massachusetts Institute of Technology some 12 years ago under the direction of Professor Jay W. Forrester. In his text, he summarizes his research as follows:

> Industrial dynamics is a way of studying the behavior of industrial systems to show how policies, decisions, structure, and delays are interrelated to influence growth and stability. It integrates the separate functional areas of management-marketing, investment, research, personnel, production, and accounting. Each of these functions if reduced to a common basis by recognizing that any economic or corporate activity consists of flows of money, orders, materials, personnel, and capital equipment. These five flows are integrated by an information network. Industrial dynamics recognizes the critical importance of the information network in giving the system its own dynamic characteristics. (3)

Using the ideas and concepts developed in this work establishes the basis on which to study the systems interaction between production-quality-sales.

CHAPTER III

THE CONCEPTUAL MODEL

The development of a conceptual model to explain production-quality-sales interactions was motivated by the desire to explain a fairly common production work-load curve. Figure 1 illustrates the symptoms of a systems problem since no rational explaination for peaks in production can be justified in a technically oriented product line.

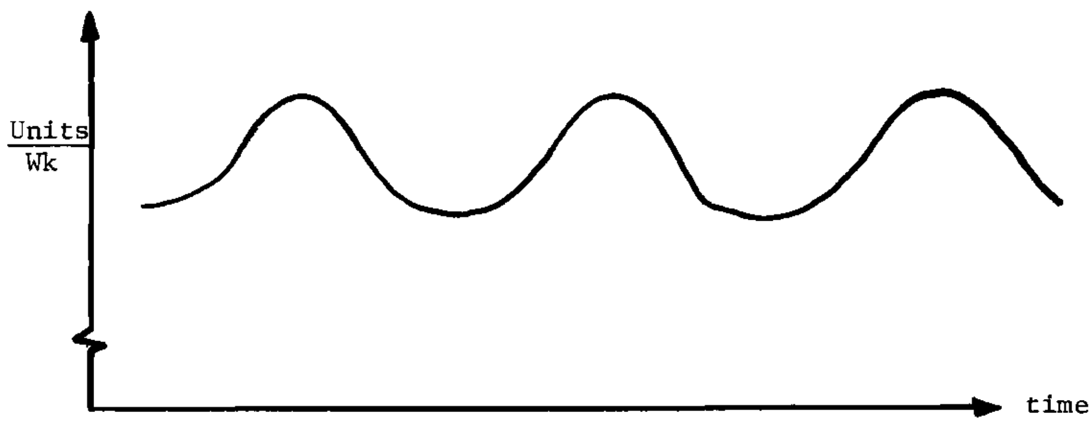


Figure 1. Production Work Load Curve

Since many companies consider themselves very quality conscious, a simulation model was hypothesized to examine the pertinent relationships in the production-quality-sales framework which could cause the observed behavior.

The controlling feedback loops were hypothesized as shown in Figure 2.

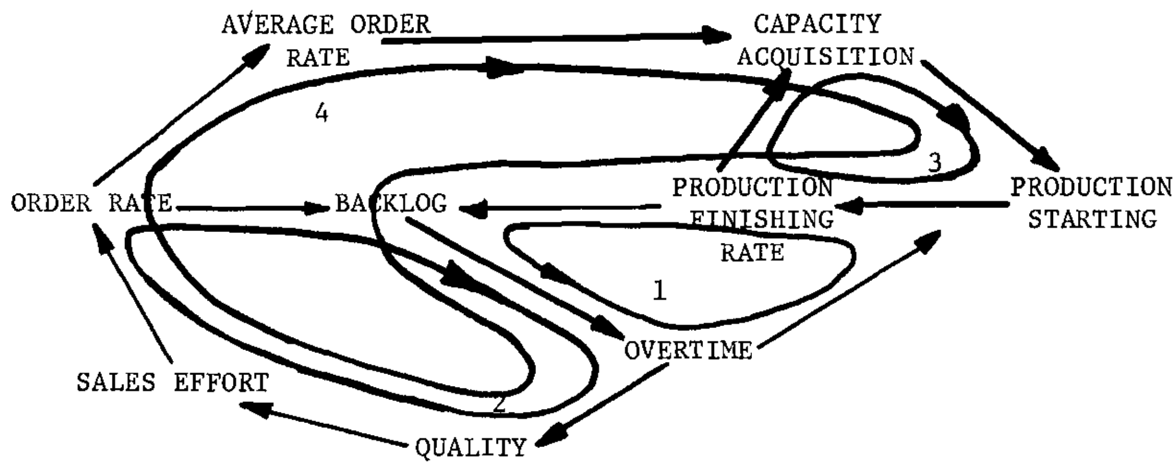


Figure 2. Controlling Feedback Loops

One positive and three negative feedback loops are presented which describe some of the dominant factors in the market-company interaction of a quality sensitive company. Positive feedback loops have a steady growth or decay characteristic, and an increase or decrease in some variable in the loop will traverse the loop and amplify that disturbance further in the same direction. Loop number four is such a loop. Negative feedback loops have a goal oriented behavior and any deviation from the desired condition is counteracted so that the desired condition is approached. Loops one, two, and three are such loops.

In general, feedback loops one and two dominate short term cyclic behavior while loops three and four dominate long term characteristics of the system. The two short term loops represent crisis loops which allow management to meet pressing delivery commitments. The long term loops describe the company's desire to expand or reduce firm capacity in response to observed market conditions.

Loop number one describes the interaction of the production process from start to finish, the backlog, and the use of overtime to meet short range production goals and commitments. An hypothesized sensitivity to the deviation of the actual backlog in reference to the desired backlog creates pressure to meet shipping deadlines through the use of extensive overtime.

Loop number two illustrates the market consequences of overtime activity in the production process. As increased amounts of overtime are used to meet delivery commitments, the ability and desire of production workers to produce at the normal quality level is affected. The resulting decrease in quality in experienced in three general areas: (1) incompleteness, (2) incompatibility and (3) equipment defects. Incompleteness refers to the omission of some integrated section of the product. Incompatibility refers to the shipment of goods which function correctly in sections but fail to mesh into the ordered integrated unit. The third case deals with the normal types of quality defects such as those experienced in defective capacitors, resistors, or other minor sub-units of the product.

Since the production and sale of a highly technical product is assumed, the sale of the product through a technically oriented sales force is considered. The salesmen have a balancing decision to make according to the policies set forth by company mandate or image, and pressures the salesmen experience due to the ability to meet sales quotas. Basically, the salesmen must allocate effort between service and repair of the product and the generation of additional sales. The decisions which are actually manifested have a corresponding effect on the orders received at the company at some future date. The orders flow into the company backlog which subsequently determines the overtime considerations. The loop as shown is a negative feedback loop since the effects of an increase in the backlog traverses the loop to cause a subsequent reduction in the backlog through the order rate.

Loop number three, a positive feedback loop, describes management's response to prolonged differences in the production rate and the ordering rate. Prolonged differences indicate an increasing or decreasing market and prompts management to increase or decrease its capability to produce units. Management would like to handle all the orders they could possibly receive, and would like to produce all such orders at the most efficient operating level - no overtime, steady work-loads, and steady employment. Loop three acts to accomplish this objective.

Loop number four, a negative feedback loop, also describes management capacity acquisition policy. Capacity is acquired in order to correct any difference in the average order rate and the average production finishing rate. When the average production finishing rate is capable of exactly meeting the average order rate, capacity acquisition is halted.

In summary, loops one and two indicate that the use of overtime to meet delivery commitments ultimately acts to keep the backlog in balance with normal production capacity. Loops three and four are long term loops which correct differences in the average order rate and the average production finishing rate by the acquisition or releasing of capacity. The entire system seems to react to pressures generated by observation of system situations. Actual control of the system is suggested to be maintained in these pressure response mechanisms which can be regulated and modified through changes in management temperment. The resolution of the system conflicts would seem to be desirable.

CHAPTER IV

MODEL FORMULATION

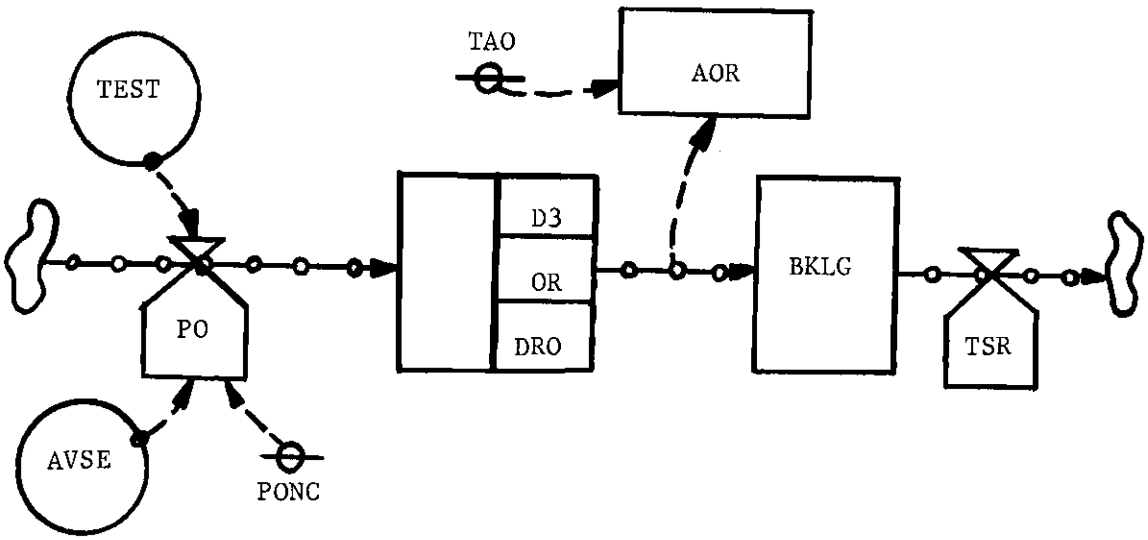
In order to be concise, the repetitive description of individual equations and equation types will be omitted from the body of the thesis. Rather a complete listing of equations, constants, initial conditions, and listing of variables is provided in Appendices A and B.

A qualitative description of considerations in the various sectors of the model will be discussed in the text of the thesis. Only those concepts in each area which could provide dramatic insight into the systems problem and formulation will be emphasized. Also included will be a sectional flow diagram using the conventional industrial dynamics flow symbols. The understanding of each sector's structure should provide the reader with a firm grasp of the model considerations. The totality of these sectional diagrams will be found in composite form in Appendix C.

Order Processing Sector

The prospective orders generated in the market serves as a convenient starting point for analysis of the system. Prospective orders are orders which will eventually be placed with the company after some processing and appropriation delay at the customer. The prospective orders actually generated will be the sum of those placed normally and the driving input function. This sum is modified to reflect the results of recent average sales effort on order generation by the salesmen.

After some delay, these prospective orders are placed and enter the company backlog of work. The backlog consists of all those orders which have been received but not filled. The backlog is subsequently decreased when units are shipped to the customer.



TEST - Test input (order per week)
PO - Prospective orders (orders/wk)
AVSE - Ave. Sales Effort (normal units/wk)
PONC - Prospective Orders Normal Constant
OR - Order Rate (orders/wk)
BKLG - Backlog (orders)
TSR - Testing and Shipping Rate (units/wk)
AOR - Average Order Rate (orders/wk)
DRO - Delay to Receive Orders (wks)
TAO - Time to Average Orders (wks)

Figure 3. Order Processing Flow Diagram

Capacity Acquisition Sector

The desire to either increase or reduce capacity in the form of additional personnel results from the perception of differences existing between the average order rate and average production capacity. A simplifying assumption in the model depicts production capacity solely as a function of the trained work force. Physical facilities are assumed available either by additional shift work or by acquisition of more machines and equipment.

Management decisions for increasing or decreasing the work force are formulated as non-linear responses to differences in the average order rate and the average production finishing rate and the need to fill the production pipeline. The difference then indicated for expansion determines the fractional increase or decrease in the work force needed to correct the disparity.

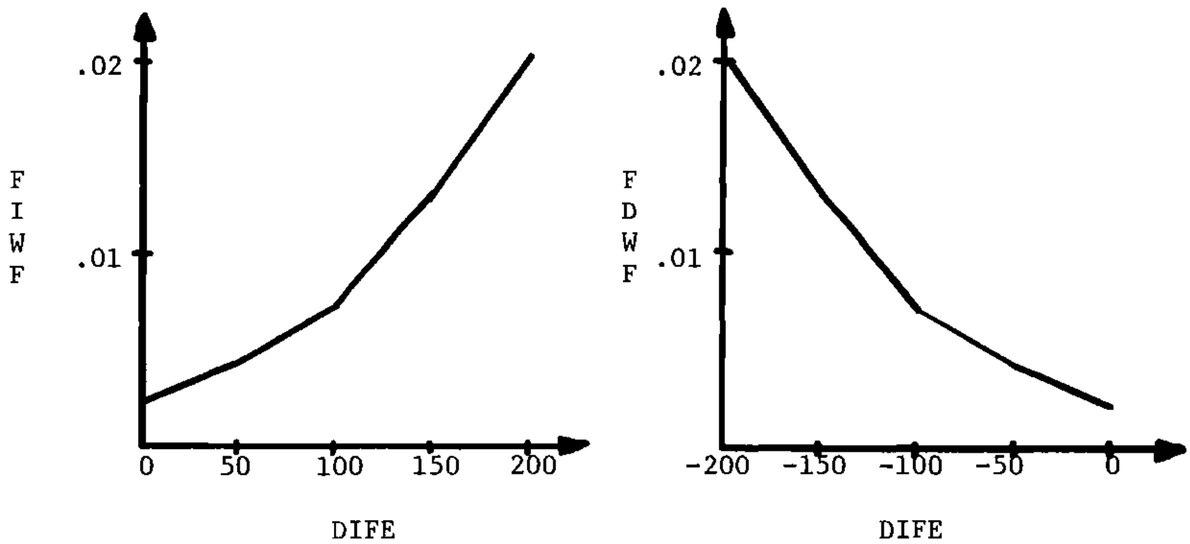
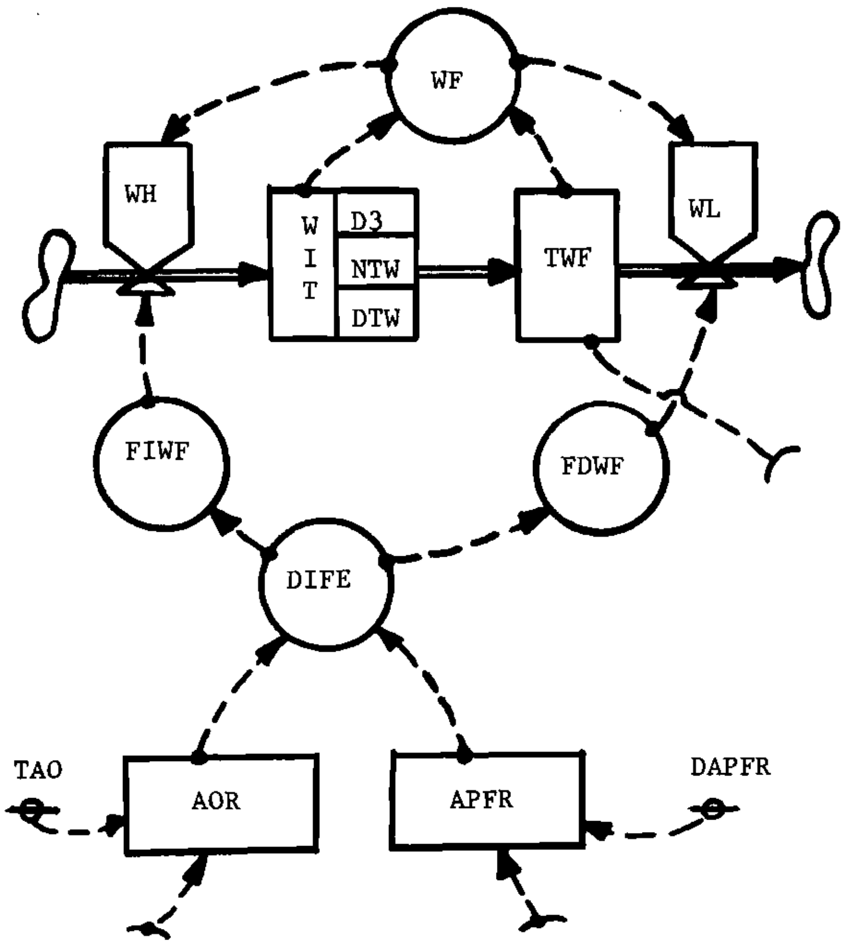


Figure 4. Hiring and Firing Decisions

The model structure of this decision sector and the work force structure follows.



WF - Work Force (men)
WH - Workers Hired (men/wk)
WL - Workers Leaving (men/wk)
WIT - Workers in Training
NTW - Newly Trained Workers (men/wk)
TWF - Trained Work Force (men)
FIWF - Fractional Increase in Work Force (1/wk)
FDWF - Fractional Decrease in Work Force (1/wk)
DIFE - Difference Indicated for Expansion (Units/sk)
AOR - Average Order Rate (orders/wk)
APFR - Average Production Finishing Rate (units/wk)
DAPFR- Delay to Average Production Finishing Rate (wks)
DTW - Delay to Train Workers (wks)

Figure 5. Capacity Acquisition Flow Diagram

Production Sector

The production sector can be modeled as a series of three appropriate departments where work production phases are carried out. The three segments selected represent a typical technical product manufacturer where many products are made to customer order: design, production, and testing and shipping. The rates at which these units flow from one department to another is determined by the delays inherent in completing each departmental task. These delays can be affected by management decision to utilize overtime activity.

Management overtime policies usually have the most dramatic effect on reducing the delays in those areas which add no tangible shape or form to the product. Testing, the area most responsible for insuring product quality, falls in this category. Therefore application of overtime to meet deadline deliveries usually reduces the testing and shipping delay considerably. Production delays are more rigid since each unit must be the result of a similiar amount of physical work. Increases in overtime essentially results in nearly linear decreases in the production delay down to the minimum production time.

The actual relationships assumed between overtime (in ratio form versus a standard 8-hour day), testing and shipping delay, and production delay are shown in Figures 6 and 7.

The flow diagram for this sector appears in Figure 8.

Overtime Determination Sector

Overtime work to meet short term delivery commitments results from various situations generated by the system and responded to by

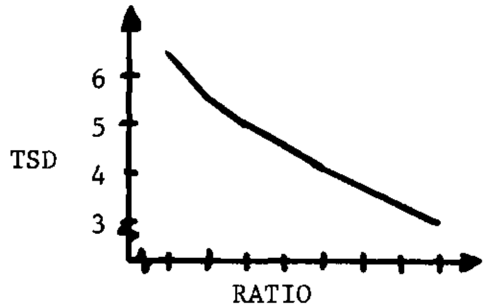


Figure 6. Testing and Shipping Delay vs. Ratio

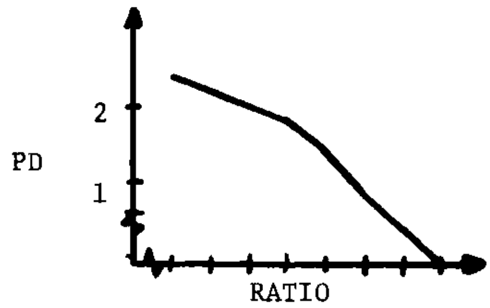
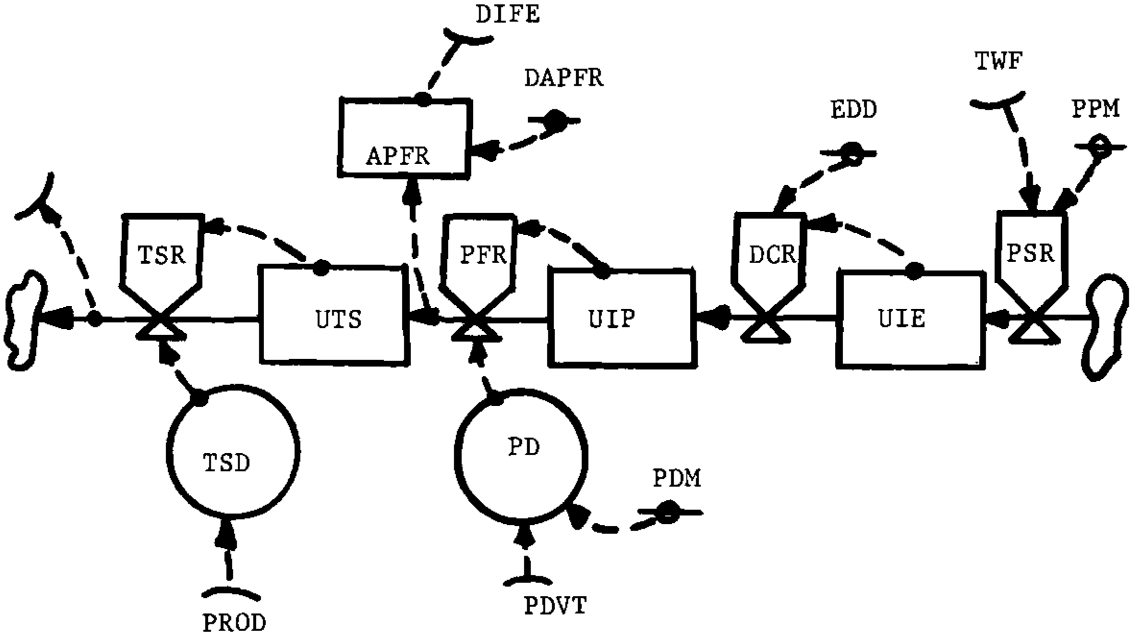


Figure 7. Production Delay vs. Ratio



APFR - Average Production Finishing Rate (units/wk)
PPM - Productivity Per Man (units/wk/man)
PSR - Production Starting Rate (units/wk)
DCR - Design Completion Rate (units/wk)
PFR - Production Finishing Rate (units/wk)
TSR - Testing and Shipping Rate (units/wk)
UIE - Units in Engineering (units)
UIP - Units in Production (units)
UTS - Units in Testing and Shipping (units)
TSD - Testing and Shipping Delay (wks)
PD - Production Delay (wks)
EDD - Engineering Design Delay (wks)
PDM - Production Delay Minimum (wks)

Figure 8. Production Flow Diagram

the controlling managers. Often the response to apply overtime results from observed differences between the desired and actual backlog. In addition, the sensitivity to that difference is non-linear since small percentage deviations cause relatively little incremental pressure in contrast to larger percentage deviations and their incremental changes.

Equation formulation describing the overtime application mechanism takes the form of a ratio determined from the division of the total testing and shipping rate desired by the normal testing and shipping rate capability. The conversion of the ratio to the overtime factor is nearly linear except at the extreme regions of the ratio.

Figure 10 is the flow diagram for the sector.

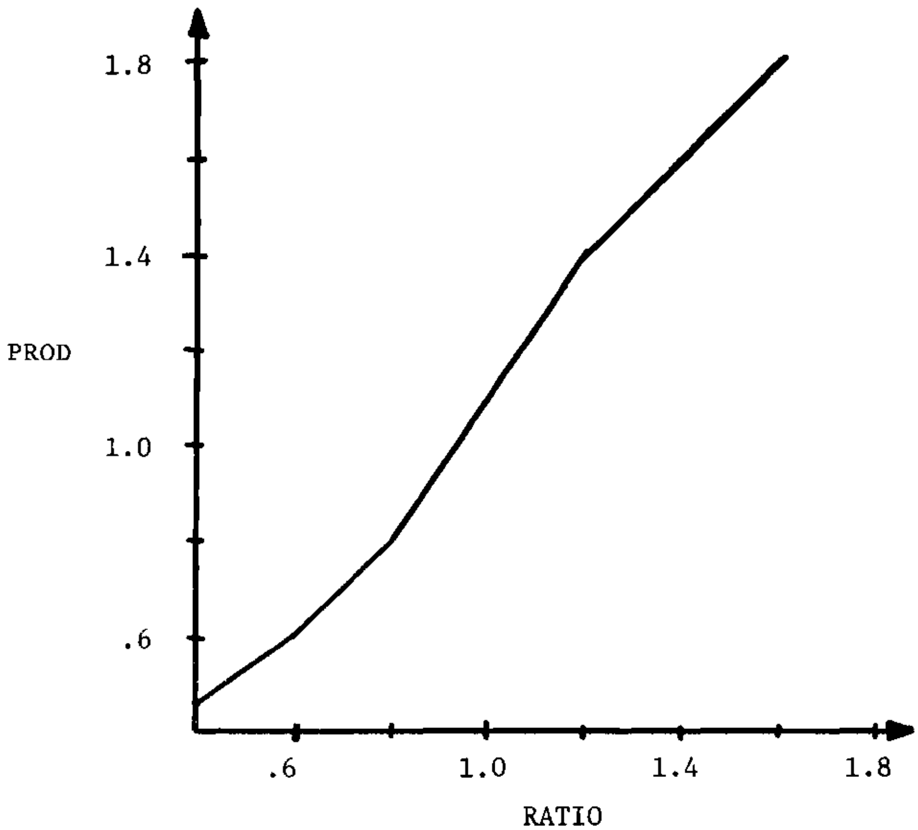
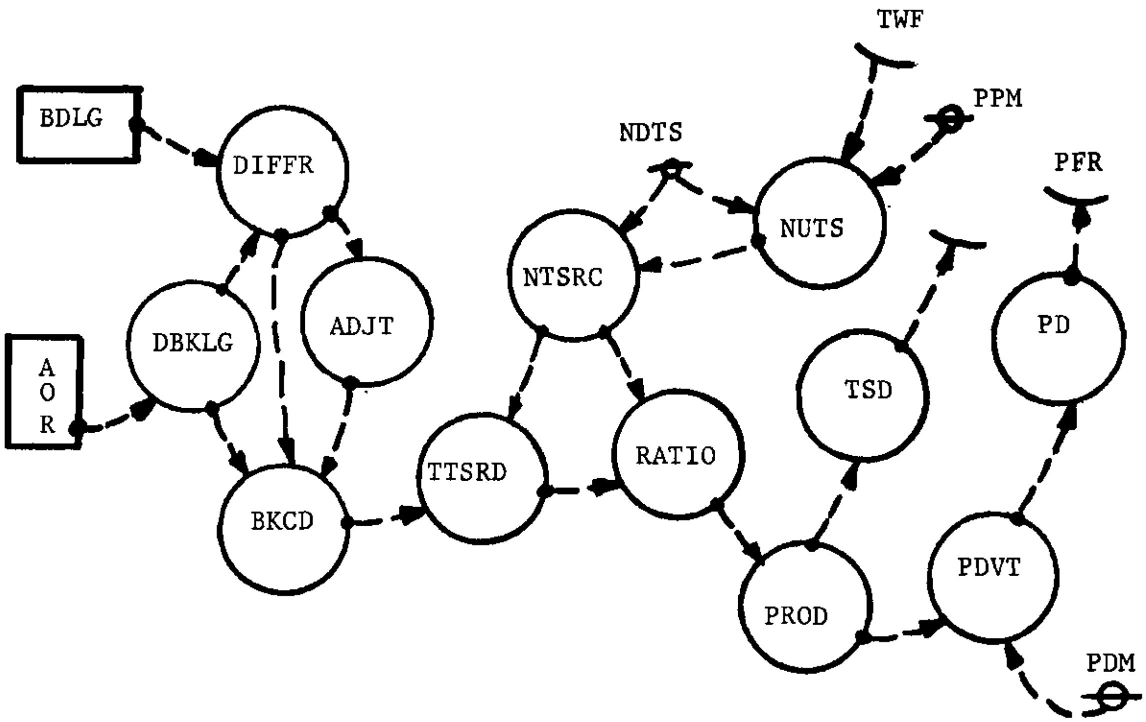


Figure 9. Productivity vs. Ratio



BKLG - Backlog (orders)
AOR - Average Order Rate (orders/wk)
DBKLG - Desired Backlog (units)
DIFFR - Difference Ratio (dimensionless)
ADJT - Backlog Adjustment Time (wks)
BKCD - Backlog Correction Desired (units/wk)
TTSRD - Total Testing and Shipping Rate Desired (units/wk)
NTSRC - Normal Testing and Shipping Rate Capability (units/wk)
NUTS - Normal Units in Testing and Shipping (units)
RATIO - Ratio of TTSRD to NTSRC (dimensionless)
PROD - Overtime to Increase Productivity (dimensionless)
TSD - Testing and Shipping Delay (wks)
PDVT - Production Delay Variable Time (wks)
PD - Production Delay (wks)
PDM - Production Delay Minimum (wks)

Figure 10. Overtime Determination Flow Diagram

Quality Sector

The quality of the product is hypothesized to be inversely related to the amount of overtime worked by the employees. Increased work loads over extended periods cause worker fatigue and subsequently, less high quality work is performed. The relationship between overtime (productivity) and quality is given below.

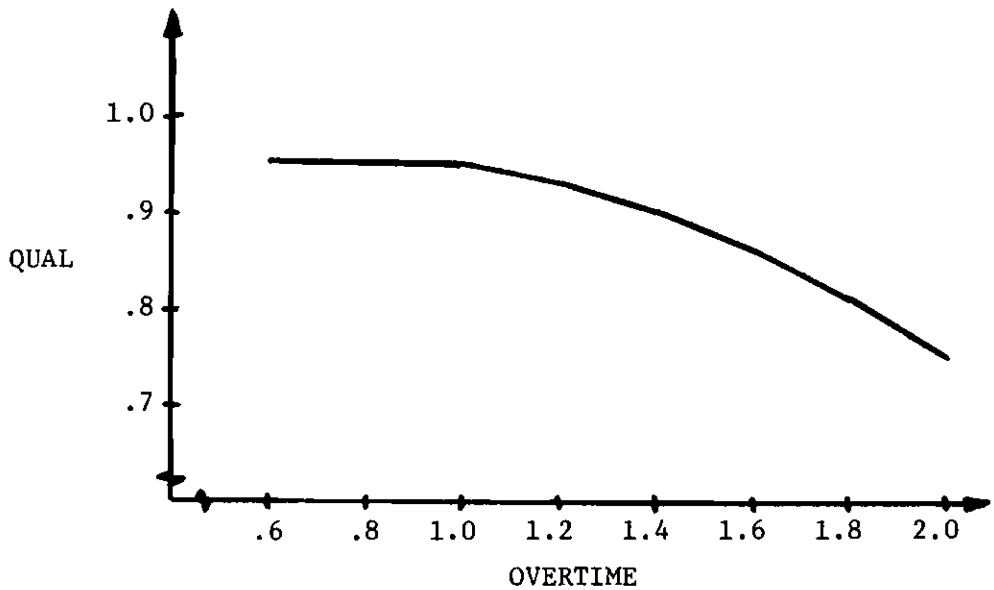
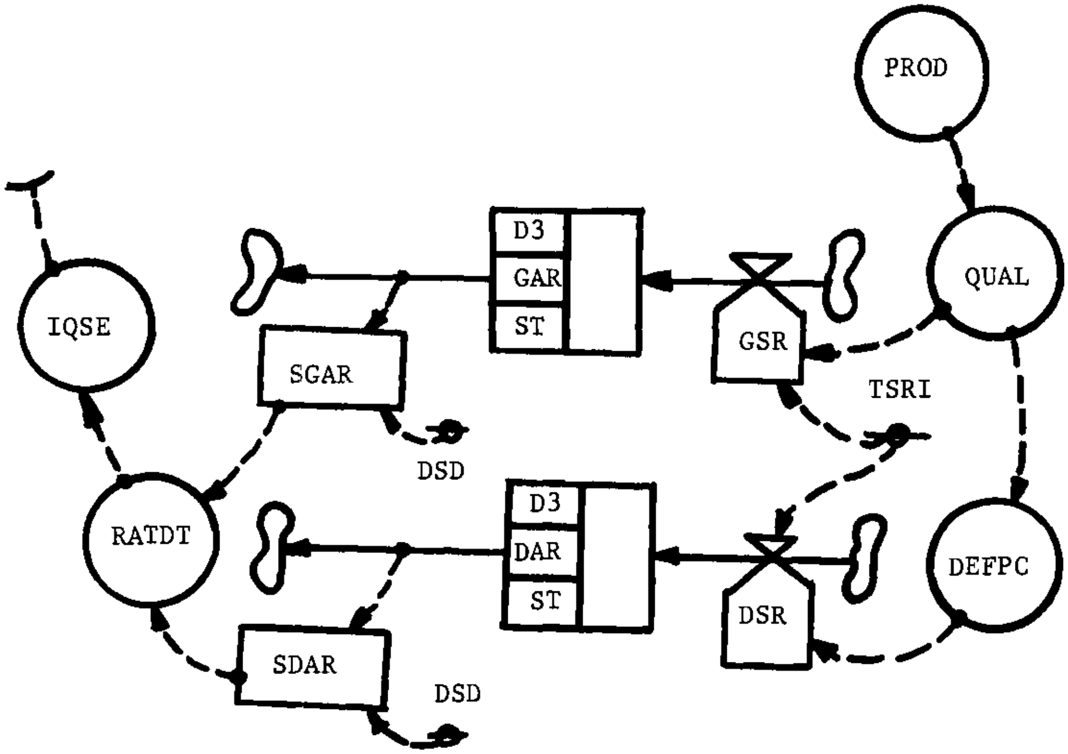


Figure 11. Quality vs. Productivity

The defective units arrive for on-site installation after a shipping delay. The defective units are discovered at this point. Customers contact the salesmen when defective units are found and it is their responsibility not only to act as liaison between the plant and customer but also seek to appease and maintain the high quality reputation of the firm and its products.

The structure representing this qualitative description follows in Figure 12.



QUAL - Quality (dimensionless)
DEFPC - Defective Percentage (dimensionless)
TSRI - Testing and Shipping Rate Indicated (units/wk)
GSR - Good Shipping Rate (units/wk)
DSR - Defective Shipping Rate (units/wk)
GAR - Good Arrival Rate (units/wk)
DAR - Defective Arrival Rate (units/wk)
SGAR - Smoothed Good Arrival Rate
SDAR - Smoothed Defective Arrival Rate
RATDT - Ratio of Defective to Total (dimensionless)
IQSE - Impact of Quality on Selling Effort (dimensionless)

Figure 12. Quality Sector Flow Diagram

Sales Effort Sector

Most salesmen essentially operate under a sales quota or standard goal of sales that should be made over some time span, usually a month. However, according to company wishes and the need to maintain reputation and build an image, the salesmen must allocate their effort between competing ends - in the case of technical sales, between sales and repair (service). If general company policy emphasizes the maintaining of reputation, service considerations will be foremost in the minds of salesmen when defective units are sent to customers.

The sales quota is not forgotten however. The salesman has a very tangible number in mind regarding the dollar volume of sales he lacks in meeting or overselling quota. Therefore when quality conditions are again acceptable, the salesman not only tries to meet the standard sales quota but also attempts to catch up the lost sales through extra effort, calling on repeat customers, or following up the most promising prospects for new business first.

In effect, the sales quota used by the plant for planning purposes causes extreme amplifying effects in a salesman's selling routine. Whereas a normal sales quota is expected from each salesman, the actual selling effort fluctuates widely around this normal. Since one defective unit necessitates more salesman time than the time required to make another sale, a slight decrease in plant quality is greatly amplified in the market. The following graphs illustrate the types of situations developed in the plant and market via the sales force. Figure 13 shows product quality at the plant. Figure 14 shows the delayed and amplified reaction in the sales force's effort on sales generation.

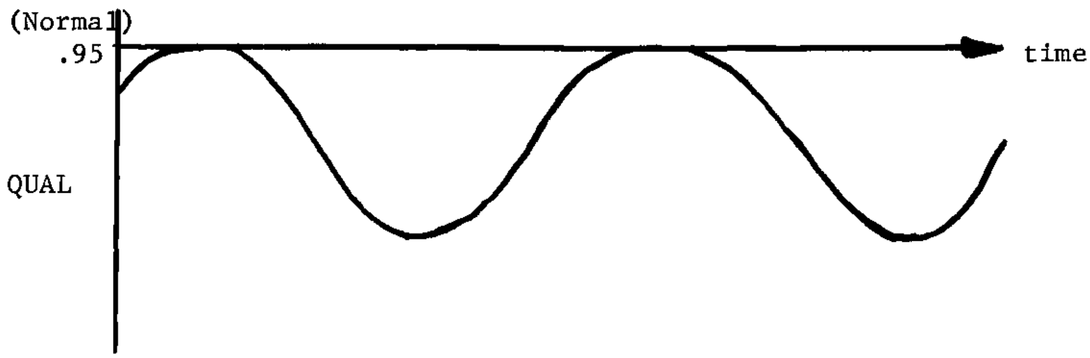


Figure 13. Quality vs. Time Relationship

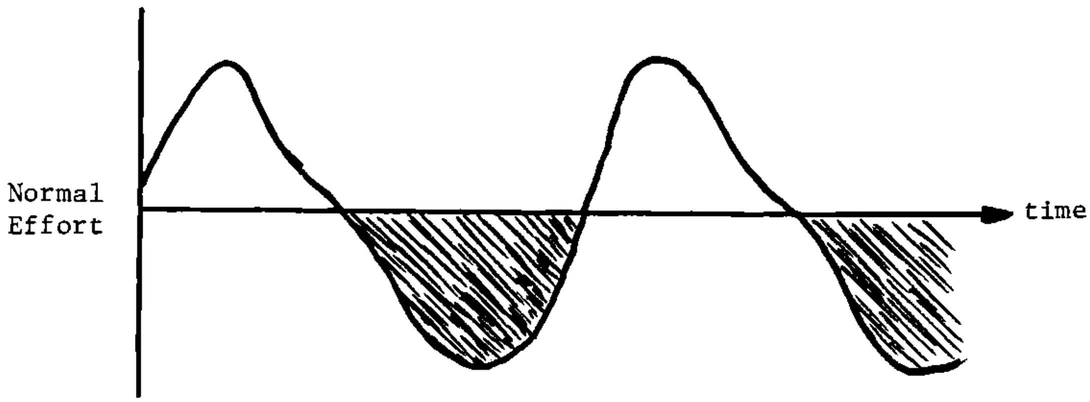
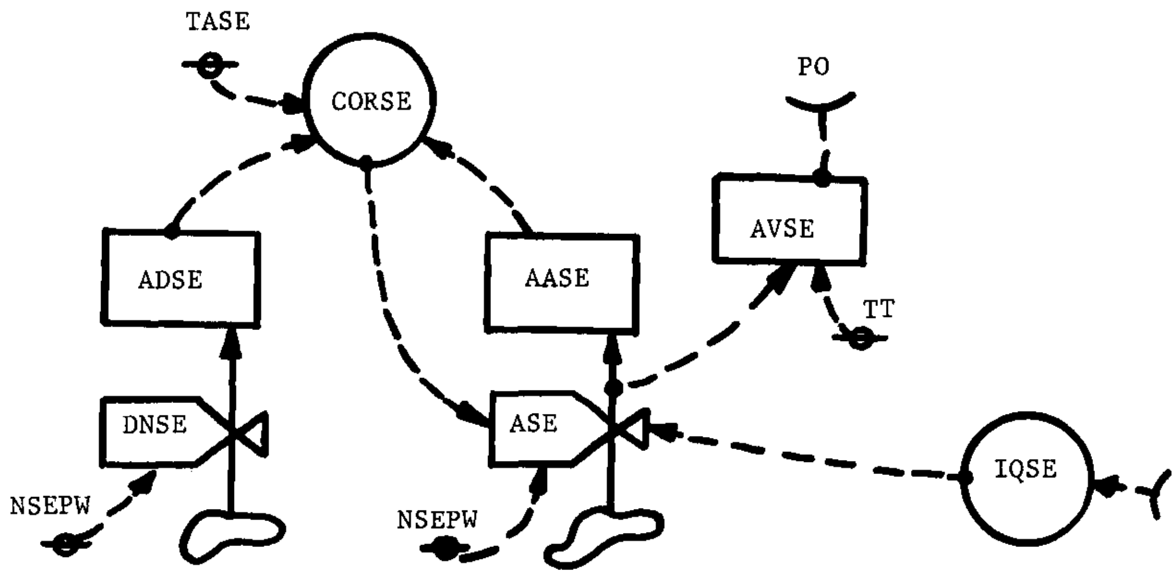


Figure 14. Sales Force Effort on Sales vs. Time

The shaded area represents the amount the salesmen have fallen behind quota due to extra service time necessitated by defective units shipped to customers. When quality again becomes normal, the shaded area is essentially distributed over some future time period to determine the sales rate necessary to maintain his scheduled average monthly quota.

The model structure depicting this pattern is shown below in Figure 15.



TASE - Time to Average Selling Effort (wks)
CORSE - Correction to Selling Effort (normal units/wk)
ADSE - Accumulated Desired Selling Effort (normal units)
DNSE - Desired Normal Selling Effort Per Week
NSEPW - Normal Sales Effort Per Week
ASE - Actual Selling Effort (normal units/wk)
IQSE - Impact of Quality on Selling Effort (dimensionless)
AASE - Accumulated Actual Selling Effort (normal units)
AVSE - Average Sales Effort (normal units/wk)
TT - Time to Average Actual Selling Effort (wks)

Figure 15. Sales Effort Sector Flow Diagram

CHAPTER V

ANALYSIS OF THE MODEL

Model analysis should provide valuable insight into the complex systems problem presented and should provide some idea of the controlling feedback loops under various model conditions. The method of analysis conducted recognizes three general areas of concentration: (1) the primary determinant of behavior is the feedback loop, (2) very few feedback loops dominate the behavior of a system at any period of time, and (3) mechanisms to transfer system dominance (usually non-linearities) among the feedback loops exist and are important to understand if we are to understand the behavior of the system itself (8).

The production-quality-sales model presented generates much of its dynamic behavior through the pressure oriented responses in management decisions. The management and sales decisions modeled have little system planning taken into consideration. The decisions are based on particular areas with no though given to the impact of that function on another. Such un-coordinated systems often have problems with the timing and phasing of the various important factors in the system such as work force, backlog, and production capability. Poor timing of the dynamic responses in the feedback loops can create patterns of behavior which lead to steady oscillations or lead to possible explosive oscillations.

The time unit selected for iterative calculations purposes was one week. The number of each week will be shown on all computer printouts as the absissa with the variables of importance being tracked over time on the ordinate scale.

Response to Various Inputs - General Behavioral Analysis

The specific behavioral patterns generated by the model are only somewhat dependent on the selection of an independent test input, in this case an increase in prospective orders. The fluctuating modes of behavior can be generated by the system structure even without a fluctuating input. However according to whether a growth trend (ramp), sudden increase (step), or other input is tested, different steady state values will result as well as slightly different settling and damping behavior. Even with noise the system, by virtue of its reactions to pressure and delays and integrations, tends to amplify those changes to which it is sensitive. Therefore the same general types of behavioral modes will be apparent in all runs.

Two basic types of input were used to test the production-quality-sales model, the step at various amplitudes and the ramp input. Each simulation showed the fluctuating work-load characteristics which were originally hypothesized. For illustrative purposes the step input was investigated at three different magnitudes: a 10% step, a 20% step, and finally a 15% step input. The 15% step input figure was arbitrarily chosen to be the driving function throughout the remainder of the model analysis. Figures 16 and 17 show the basic model behavior to the 15% step input in prospective orders. Four variables are tracked on Figure 16: (1) quality represented by Q, (2) order rate represented by O, (3) testing and shipping rate shown as T, and (4) average sales effort on sales shown as V. Only three variables are followed in Figure 17: (1)

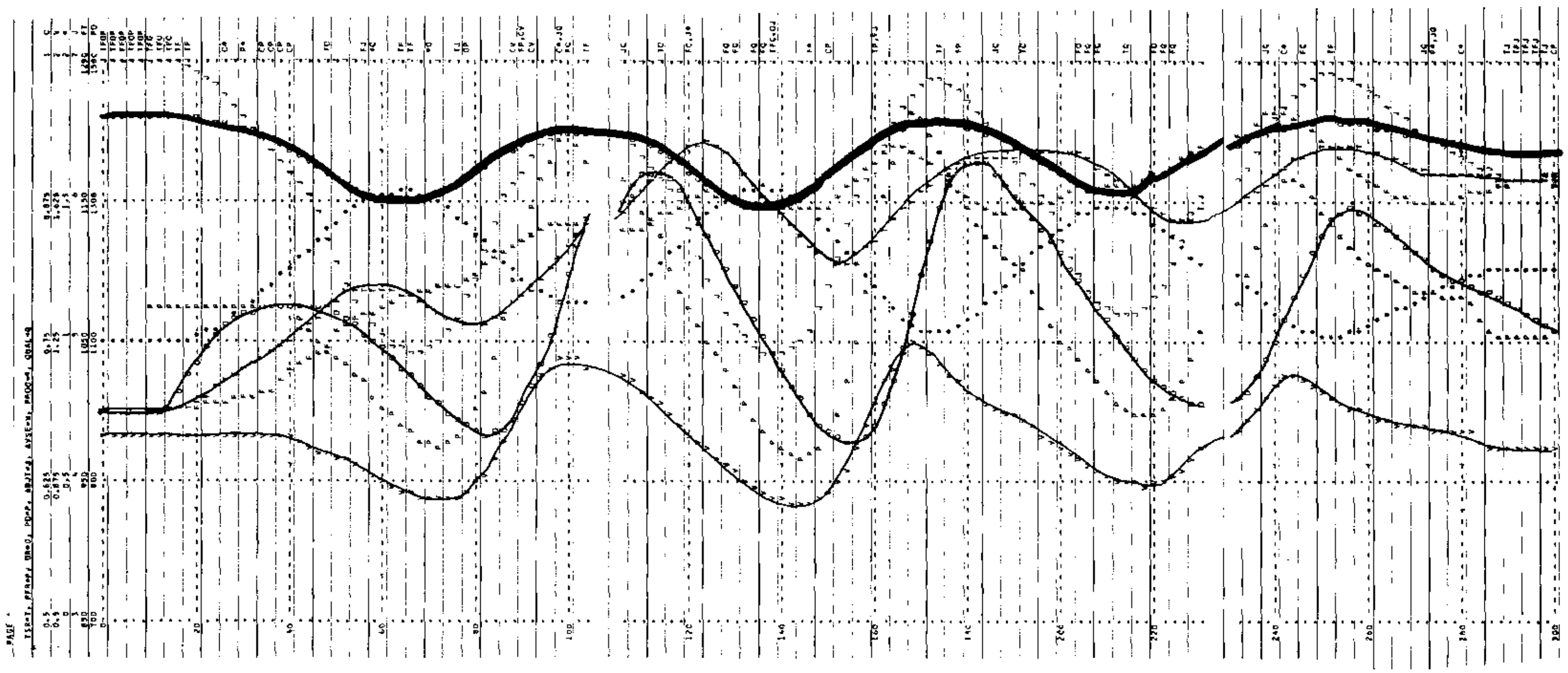


Figure 16. Original Model With 15% Step Input (Plot A)

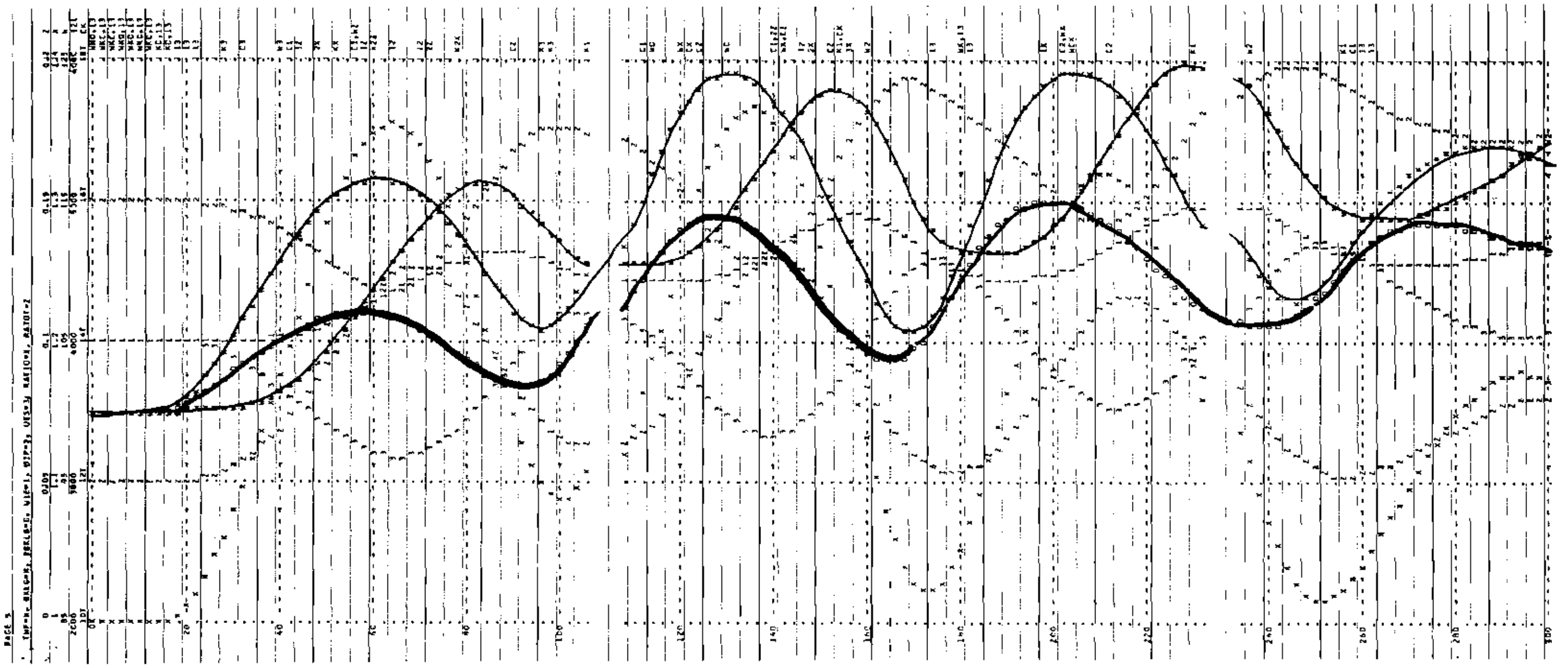


Figure 17. Original Model With 15% Step Input (Plot B)

backlog denoted by K, (2) desired backlog denoted by D, and (3) trained work force represented by W.

The 15% step input in prospective orders at time 10 immediately sends the system into its characteristic modes of behavior. The system examined using the assumed delays and structure has a period of approximately 66 weeks. The system essentially reaches steady state after the fourth oscillation when the 15% step input is used. Although computer printouts are not included in the thesis, changing of the input magnitude only affects the magnitude of the oscillations and the length of time before reaching steady state. Increasing the step to 20% results in more violent swings in all the variables and the model has only begun to reach steady state at time 300. In constrast, the 10% step input has less violent swings than the 15% step input and the model essentially reaches steady state after three periods at time 230.

Although a step input will show all the factors of importance and their behavior, a steadily increasing function is used as the driving function in Figure 18. The system sluggishly reacts initially but by time 140, the system's dynamic behavioral modes are being revealed. These are essentially the same patterns resulting from the step inputs. In order to remain consistant, the step will be the driving function in the remainder of the runs.

Referring again to Figure 16 and Figure 17, a more detailed description of the behavioral patterns will be presented. At time 10 the model receives the 15% step input in prospective orders. These prospective orders are slowly received at the plant and enter the plant backlog. The order rate reaches its first peak at time 40, but begins

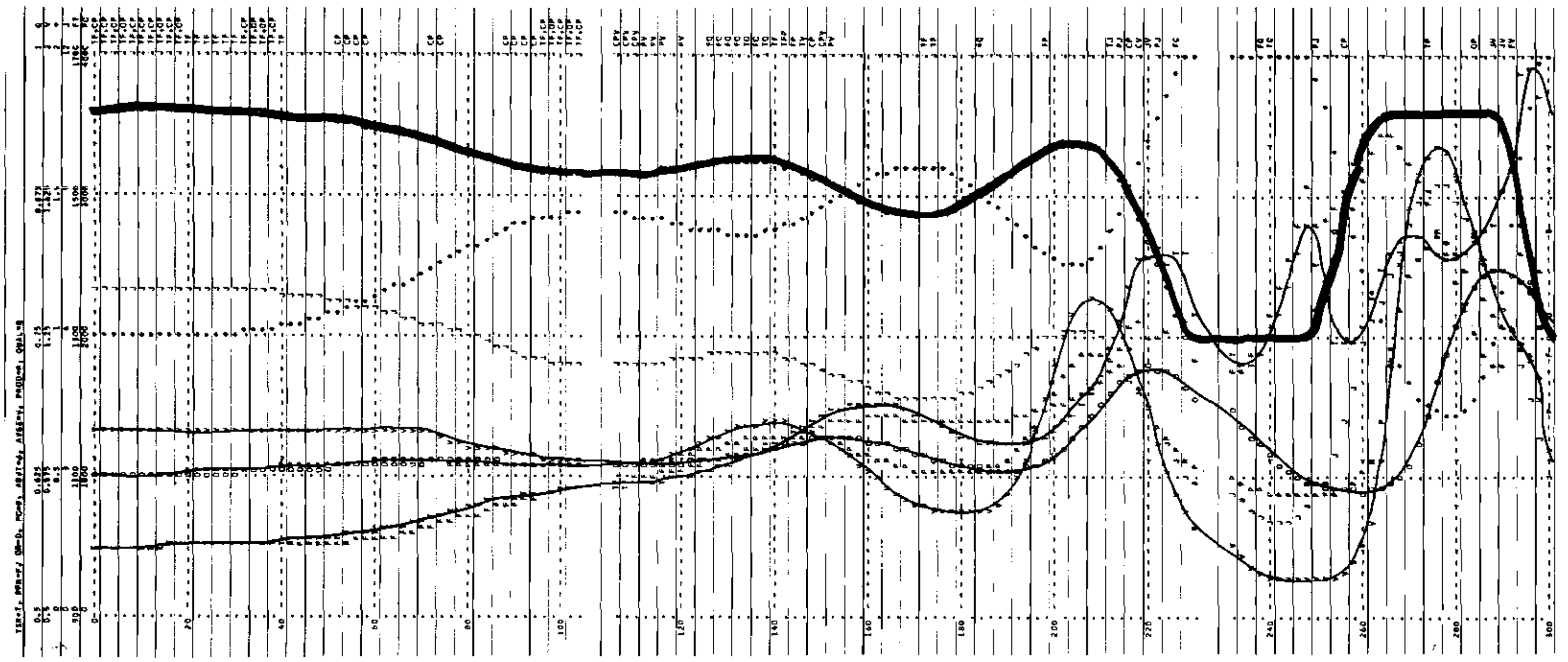


Figure 18. Original Model With Ramp Input

to decrease when the sales effort on sales has decreased such that prospective orders are falling off (time 40). From Figure 17 the actual backlog continues to grow at time 40 even though the order rate is decreasing and the testing and shipping rate is increasing - the opposite of what is the intuitive result. This result comes about because of the physical integration process of accumulating the backlog. The integration process immediately introduces a 90 degree phase shift between the level and its rates in addition to other phase shifts caused by various delays. Meanwhile the difference between the actual and desired backlog grows and reaches a peak (time 60) after the backlog situation has been corrected - decreasing order rate and increasing testing and shipping rate. The larger difference creates pressures within the organization to correct the excessive backlog. Management decides to use overtime to correct the difference and meet short term delivery commitments. Thus from Figure 16, overtime, indicated by *, has increased to 1.25 by time 40 and reaches 1.5 before the first period is over.

Although overtime can be flexibly used to meet delivery commitments, its continued use usually indicates the need for expansion of the trained work force. By finding the difference in long term average order rate and average production finishing rate, management gets some measure of desired expansion and hires or fires workers accordingly. From time 16 to approximately time 66, expansion is indicated. Note that the average order rate is decreasing at its most rapid pace at this point. Unfortunately the workers have been hired during this interval, especially the latter, as seen in Figure 17. Again as in the case of the backlog, the level of trained workers continues to increase although expansion is actually indicated as negative. At time 80 the number of trained workers is at its maximum value but the order rate is at its minimum value.

The order rate decreases as a sales force response to decreased quality sent to customers. When overtime is used at the plant to meet shipments (time 40-80), the quality and craftsmanship of the work also decreases. This decreased quality results in a gradual shift in sales force allocation from sales generation to service requirements. From time 40-66 the sales force increasingly uses more than normal time on service and correspondingly falls behind set sales quotas. As quality at the plant and its delayed appearance at the customer continues to increase, the salesmen strive not only to meet normal sales quotas but also to make up for a portion of the work on sales which has been neglected. Thus, from time 84-120 salesmen work more than normal on sales so as to meet sales quotas. The cycle completes itself at this point and similar conditions exist in the model as did originally.

System Behavior With Changes in Certain Parameters

Within the structure of the initial model, certain constants, averaging times, and table non-linearities were assumed. Before further analytical and statistical tests are needed to determine more accurate data, a simulation type of sensitivity analysis was conducted to find those parameters which had the most dramatic effect on behavior. By contrasting the changes in parameters with the original model, the effect of the parameter on total system behavior can be assessed.

One critical area of the model, quality, was assumed to be a function of the amount of overtime being used to meet delivery commitments. Figure 19 shows model behavior using the assumption that quality is constant for all amounts of overtime - or where quality may vary but have no effect on the sales forces' balancing of effort between sales and service. Under these two model conditions, the testing and shipping rate has little overshoot and little instability. Overtime increases initially to reduce the backlog but there is little oscillatory behavior in overtime application. Figure 19 as contrasted with Figure 16 shows that very dramatic dynamic responses and behavior patterns are created in the quality-sales sector.

Other runs not included in the thesis indicate that the actual table values assumed for the relationship between overtime (productivity) and quality are relatively unimportant as long as some factor indicates that quality does drop when overtime is increased. A reasonable range of values within 20% of the original model table shows little effect on total system performance.

The sales effort allocation sector of the model seems to be relatively important in determining the behavior of the overall model. The sales forces' prime objective is the maintaining of the "high quality product" image of the company while the secondary objective remains the sales quota. It was found that longer trends in this sector actually caused greater instability in the system (Figure 20). When the time to average the sales efforts' impact on sales is long as in Figure 20 or when the time to adjust lost sales increases, the order rate experiences more prolonged trends. The increased periods cause greater amplitudes to develop in the backlog accumulation and also in the work force sector.

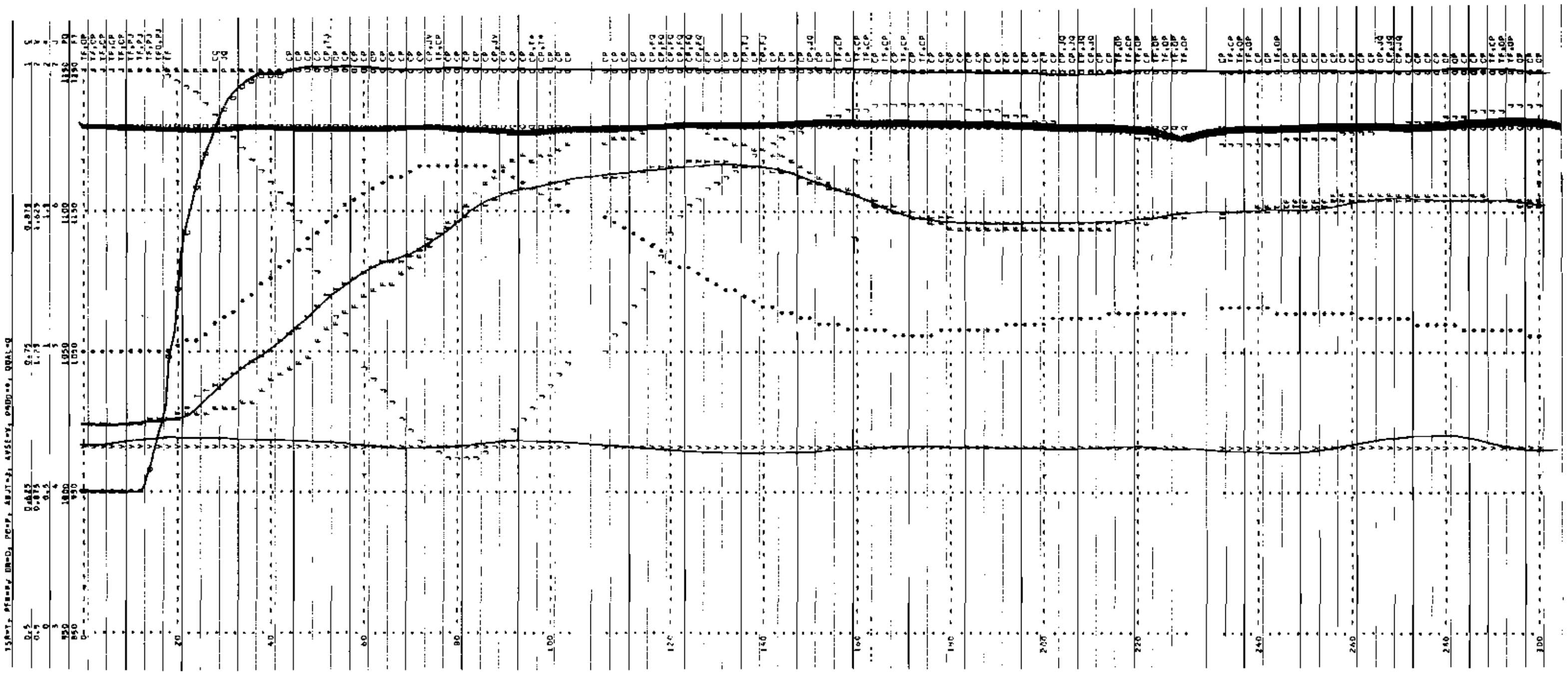


Figure 19. Model With Quality Constant

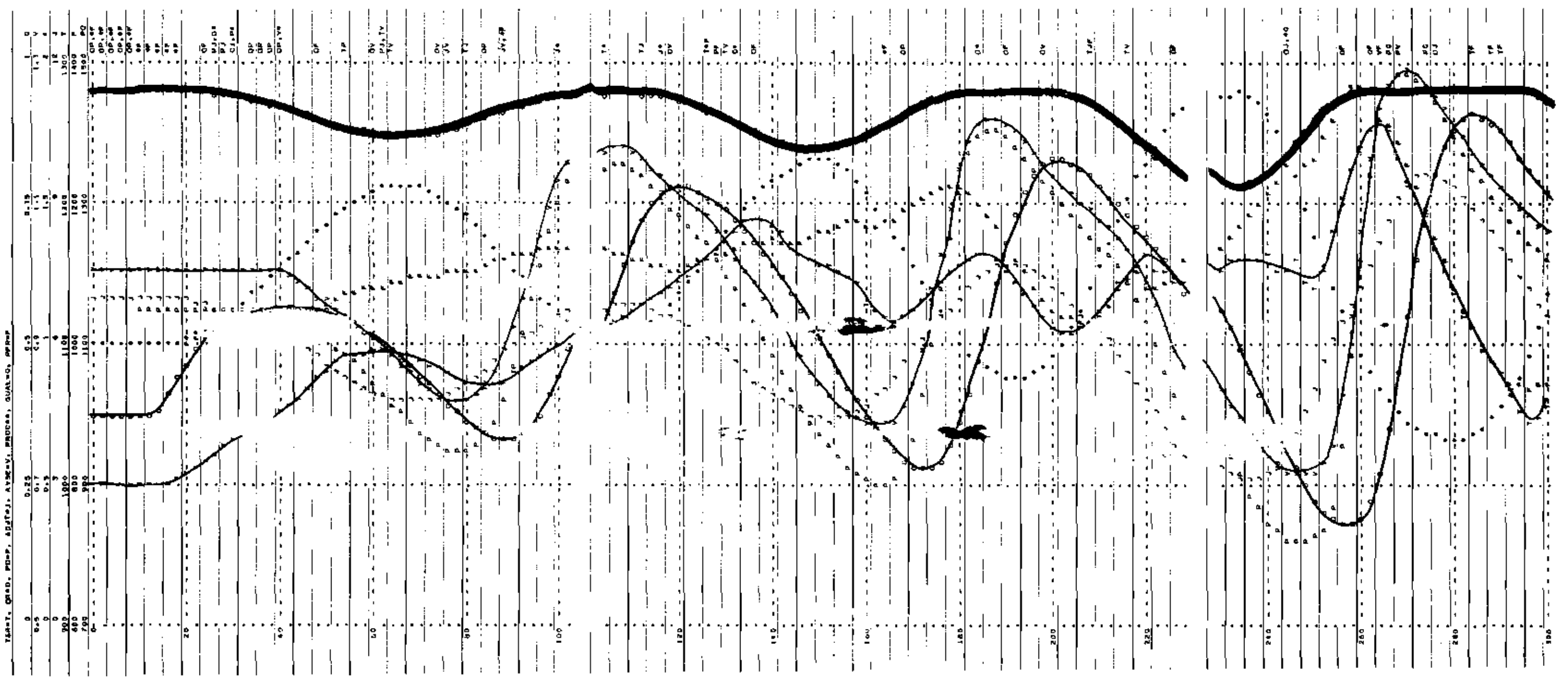


Figure 20. Model With Longer Averaging Time For Sales Effort

Because of phasing problems introduced by these longer trends and resulting greater magnitudes, considerable over and under shooting of steady state values takes place. The over and under shooting can be explained through analyzing the dominance of the different feedback loops and analyzing when each has dominance of the system. In the situation presented the positive feedback loop in capacity acquisition takes dominance of the entire system and causes increasing peaks and valleys in the production cycle. The loop switches from dominant positive to dominant negative as the loop monitoring production finishing rate either exceeds the average order rate or falls below the average order rate. Again phasing between these two loops creates many unique performance patterns when they are regulated such that they are strictly in phase or strictly out of phase. Generally both the longer averaging time of sales effort effect on sales and the longer sales adjustment time create some marginal type of explosive oscillations because of the phase relationship of the two loops.

Controlling the dominance of the capacity acquisition loops seems to be the key in the control of the model. Without control in these loops, the system soon would oscillate so violently that the company would probably be forced out of business. Two other factors which were found to have an effect on either damping this loop or failing to damp the loop, were the delay to receive prospective orders from the customer and the delay to train new employees. The results of increasing both of these are shown in Figures 21 and 22. In each case the system progressively widens the difference between the average order rate and the average production finishing rate (F), producing violent action in the

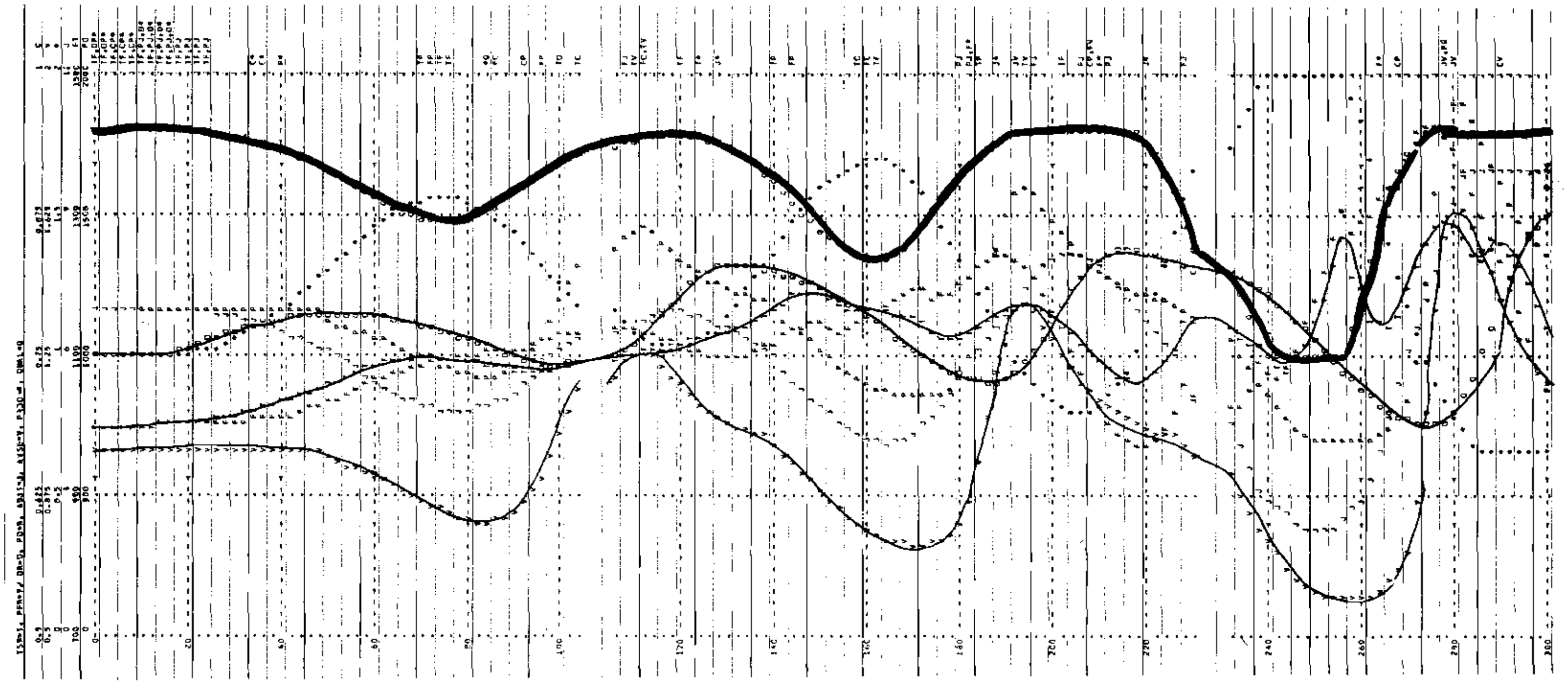


Figure 21. Model With DRO Longer

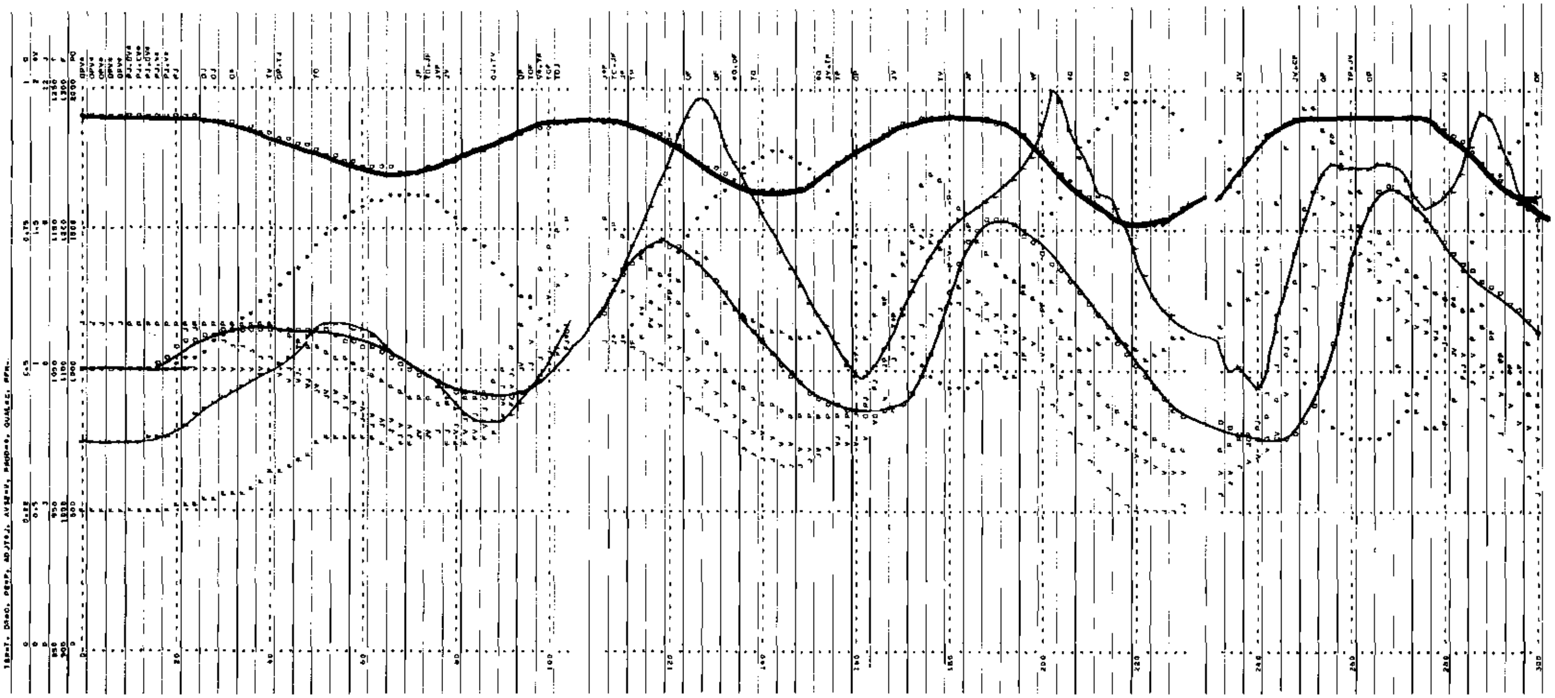


Figure 22. Model With DTW Longer

capacity acquisition loops.

The original model had adequate control of the capacity acquisition loop and the steady state of the new input was reached without undue oscillation. However, the magnitude of the oscillatory behavior can be affected by the sensitivity the company has to backlog adjustments, that is, the time the company takes to adjust actual backlog to the desired backlog. In Figure 23 below, the original model sensitivity and a high and a low estimate are shown.

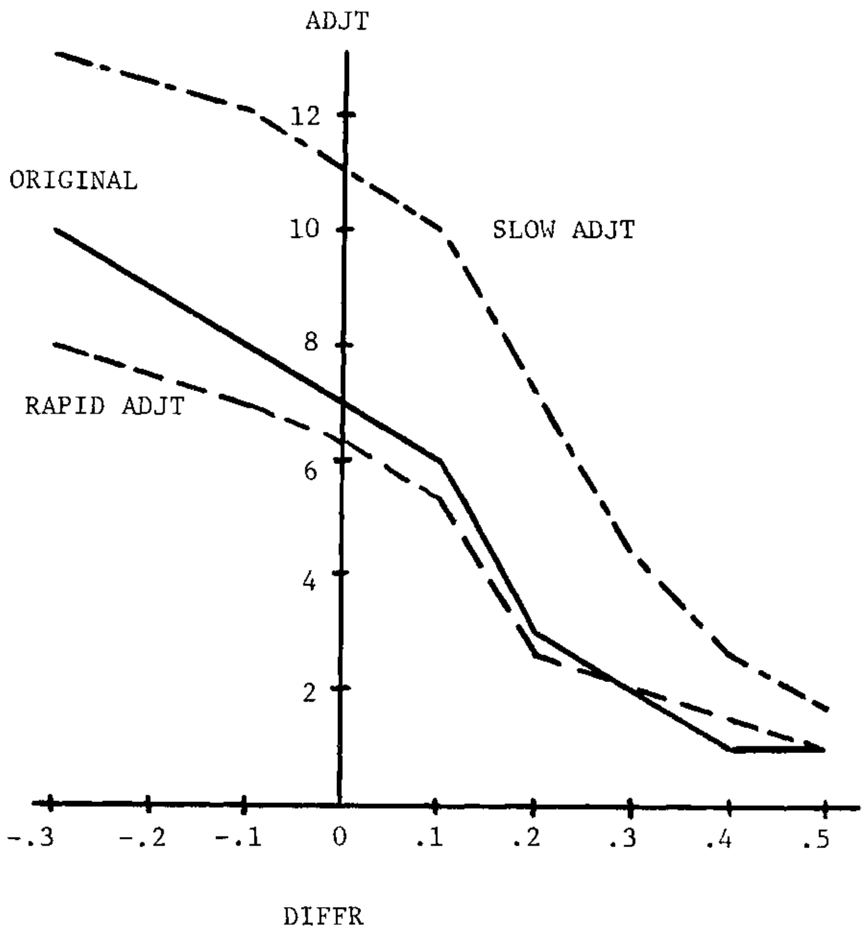


Figure 23. Backlog Adjustment Time vs. DIFFR

The simulation runs appear in Figures 24 and 25. The run with the more rapid adjustment time shows a much greater amount of instability than the run with a slow adjustment time. These runs then illustrate the trade-off which must be made in any type of control system. For greater stability, one must sacrifice responsiveness; and for more responsive behavior, one must sacrifice stability. These runs also point out an assumption which has not been stressed up to now. That is, the business field mentioned was assumed to have only mild concern for delivery delay. In the case of a slow adjustment time, little instability in the model is seen but the corresponding time to receive an order would have increased. In this model no loss in orders resulted, which is probably slightly non-descriptive. The more rapid adjustment time has the characteristic of a company also responsive to delivery delay, assuming the desired backlog is one which generates a competitive delivery delay. In this instance the company realizes that increases in backlogs result in lost orders.

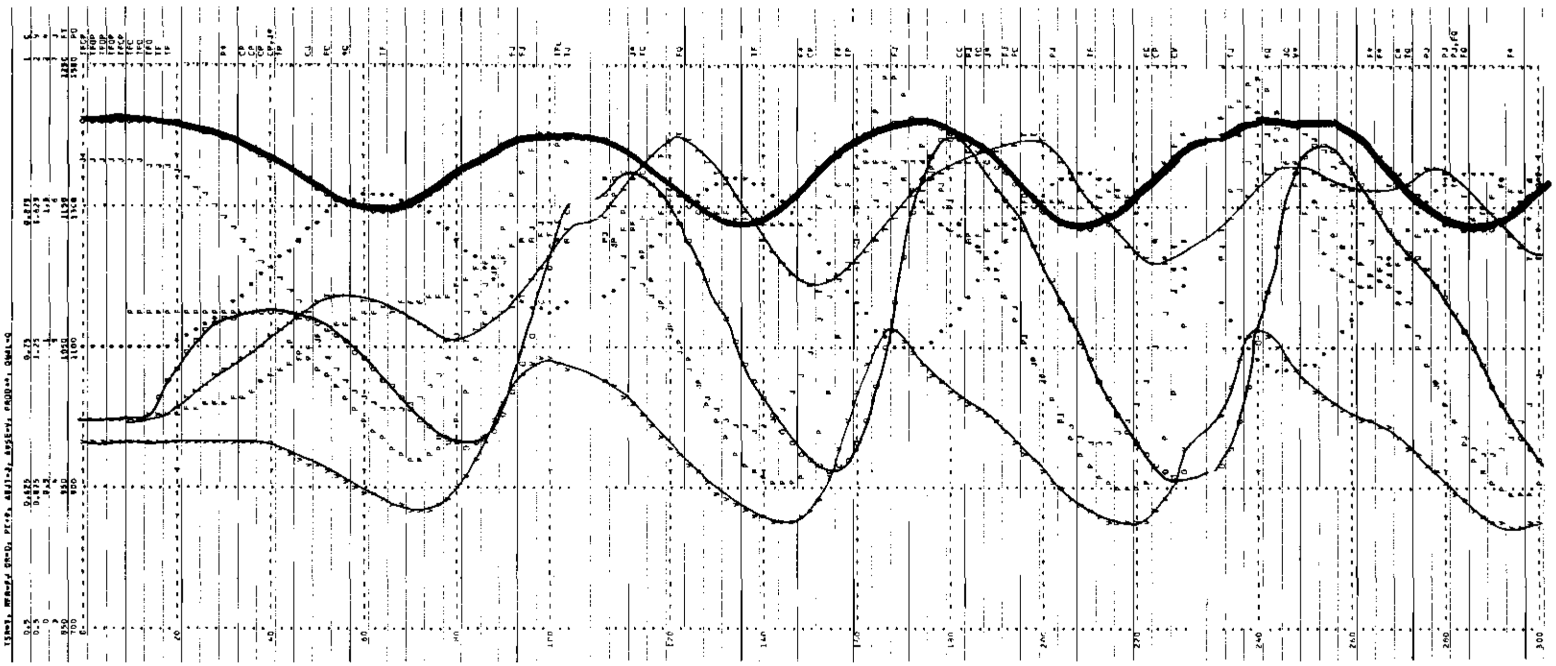


Figure 24. Model With Rapid Backlog Adjustment Time

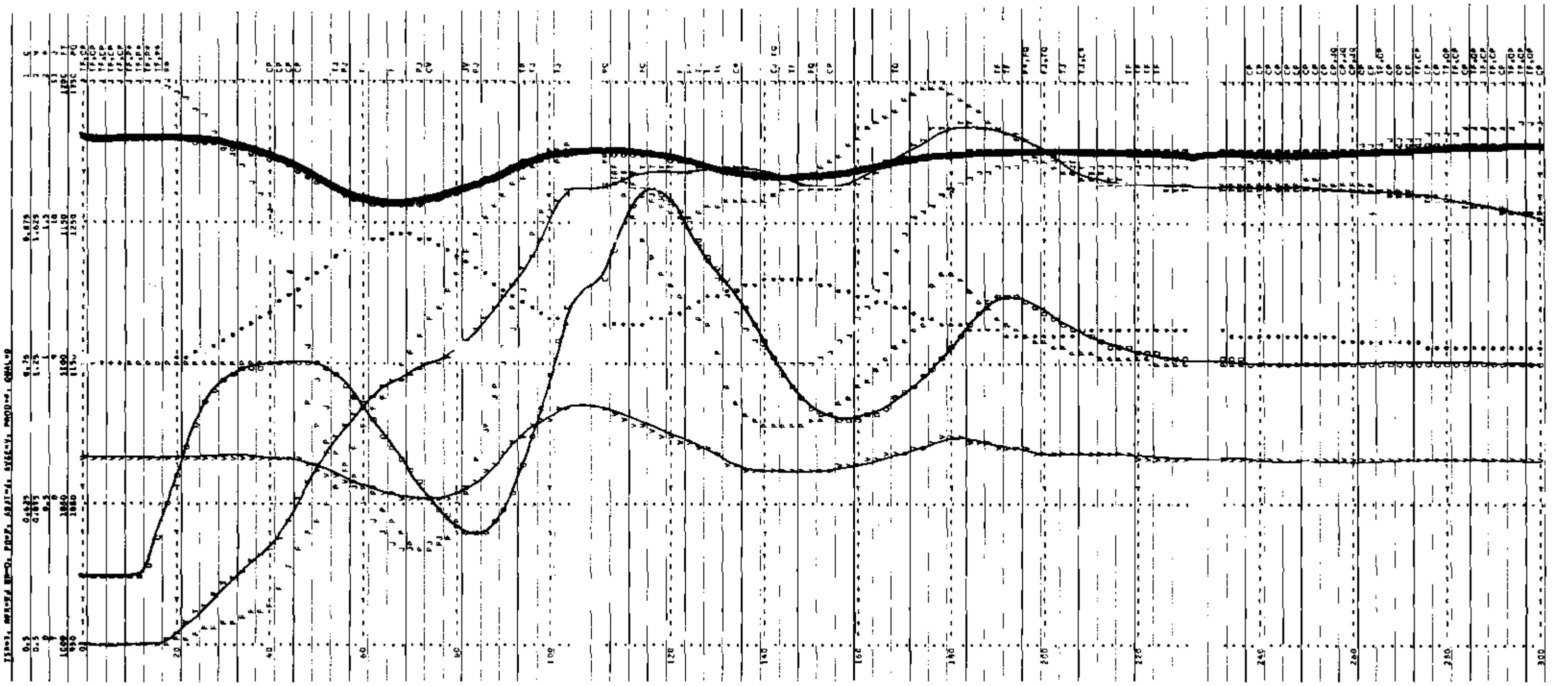


Figure 25. Model With Slow Backlog Adjustment Time

CHAPTER VI

CONCLUSIONS

In order for the field of management to show real progress in moving from an art to a science, management must create an underlying framework of principles upon which a general understanding of business systems can develop. The foundation for the advances should be easily understood by management, and should use the experience and intuition of successful managers in the structuring of this base. In coordination with these managers, the science of control and its characteristics should provide the scientific methodology necessary to describe patterns of growth, oscillation, and stagnation.

Until a methodology which explains the generality of the controlling factors which create dynamic behavior is accepted, management will remain a judgemental process developed only through extensive practical experience. However the increasing need for greater numbers of managers with greater capability places an overbearing necessity on transferring the wealth of experience and intuition of present managers to the present and future management aspirants. At present, experience is our only teacher in complex business systems decision making, thus limiting the potential management market to a small growth rate of new managers of sufficient capability. In addition, experience often fails to provide the necessary background in analyzing dynamic behavior of complex systems. Many managers, although they have years of experience, still make decisions to relieve problems only under crisis or through mere guess as to the outcomes. Such situations as these are more prevalent than many managers admit although history proves the opposite. Many decisions made have no utlimate effect on the problem the decision was made to correct, or in some cases the effects produced are even detremental. Therefore the management experience gained is not necessarily the most advantageous or the most informative.

The particular model hopefully illustrates the problems which can result (1) specifically in the interactions of the production-quality-sales interface and (2) more generally in the whole idea of management by systems. The analysis of the model points out the problems in the particular area of production, quality as it relates to overtime, and the sales effort balancing decisions and its effect on the order rate. Poor coordination of these separate entities is capable of creating many seemingly unsolveable problems. These problems do have solutions, but the managers having the authority and responsibility to solve these problems must be willing to orient their thinking into systems methodology of analysis.

Some of the specific conclusions which can be made in light of the thesis research are naturally broad since systems problems of this nature usually are broad in scope. First, the system as a whole seems quite sensitive to the desire of the company to adjust the backlog to desired values. High adjustment times create a more stable production-quality-sales relationship but could also indicate a more non-competitive delivery delay. Conversely, low adjustment times produce more system instability. Secondly, the degree to which the backlog builds and goes into the non-linear region of the backlog adjustment time causes oscillation and growth characteristics which are violent and seemingly uncontrollable. The manner in which this backlog grows is affected by the integration process inherent in accumulating the level of backlog. The backlog accumulation seems to cause extreme problems when the order rate is larger than the testing and shipping rate for prolonged periods of time. This situation is enhanced through the use of overtime and its subsequent effects on production and on sales effort allocation.

Hopefully, the model has shown that a feedback and control system approach to business can and should always be considered when operating in any complex social or business environment. The feedback and control process is universal in scope and the understanding of the implications of such a statement could ultimately lead to effective control of many phases of society.

CHAPTER VII

RECOMMENDATIONS

This thesis only touches the surface of understanding the complex systems behavior in the production-quality-sales interaction. Further modification, refinements, and extensions of the model could lead to new understanding in this area.

Substantial work could be undertaken in the validation of the model and various relationships in the model which could produce drastic changes in system performance. Additional time could be spent collecting data on periods of cyclical behavior of technically oriented sales industries, the amplitudes of such behavior, the phasing of various rates and accumulations, and the generalized decision functions which could be common to most of the companies experienceing the same symptoms. In addition, specific operating data on the sales force balancing decision, the sensitivity to backlog, and hiring and firing decisions could be gathered and tested.

In coordination with the validation of the model, restructure of some areas of the model could lead to further clarification of the coupling mechanisms between the loops and the manner in which the loops transfer system dominance. The coupling of the capacity sector to the production sector through a productivity per man constant may be changed to provide a more realistic situation where production capacity is measured in terms of both employees and capital equipment. The non-linear coupling mechanism of productivity to the production process creates a set of oscillating enclosing envelopes around other level and rate oscillations. The exact understanding of more general types of non-linear coupling mechanisms could be studied to gain additional insight into possible systems problems created by such a connection in the loops.

Apart from further efforts in this specific direction, extensive work in the study of individual general feedback loops should be undertaken. The objective of such work would be to allow a system designer to quickly synthesize, predict, and analyze complex systems. A desirable end to such work would be the development of guides for which the system designer could ask pertinent questions when the synthesis of the basic model is taking place.

APPENDICES

APPENDIX A

LIST OF MODEL EQUATIONS

```
$*      D001-001,DYN,TEST,2,4,0,0 IND DYNA TEST MODEL BY J E KNIGHT

             PRODUCTION QUALITY SALES INTERACTIONS

        INPUT SECTOR

45A     TEST.K=STEP(150,10)

        ORDER PROCESSING SECTOR

18R     PO.KL=(AVSE.K)(PCNC+TEST.JK)
39R     OR.KL=DELAY3(PO.JK,DRO)
1L      BKLG.K=BKLG.J+(DT)(OR.JK-TSR.JK)

        CAPACITY ACQUISITION SECTOR

3L      AOR.K=AOR.J+(DT)(1/TAO)(OR.JK-AOR.J)
3L      APFR.K=APFR.J+(DT)(1/DAPFR)(PFR.JK-APFR.J)
58A     FOWF.K=TABHL(TFCW,DIFE.K,-200,0,50)
58A     FIWF.K=TABHL(TFI,DIFE.K,0,200,50)
7A      DIFE.K=A.K+B.K
7A      A.K=AOR.K-APFR.K
20A     B.K=E.K/RR
7A      C.K=BKLG.K-UIE.K
7A      D.K=-UIP.K-UTS.K
7A      E.K=C.K+D.K
12R     WH.KL=(WF.K)(FIWF.K)
12R     WL.KL=(FOWF.K)(WF.K)
39R     NTW.KL=DELAY3(WH.JK,DTW)
1L      WIT.K=WIT.J+(DT)(WH.JK-NTW.JK)
1L      TWF.K=TWF.J+(DT)(NTW.JK-WL.JK)
7A      WF.K=WIT.K+TWF.K

        PRODUCTION SECTOR

12R     PSR.KL=(TWF.K)(PPM)
1L      UIE.K=UIE.J+(DT)(PSR.JK-DCR.JK)
20R     DCR.KL=UIE.K/EDC
1L      UIP.K=UIP.J+(DT)(DCR.JK-PFR.JK)
20R     PFR.KL=UIP.K/PC.K
1L      UTS.K=UTS.J+(DT)(PFR.JK-TSR.JK)
20R     TSR.KL=UTS.K/TSD.K

        MANAGEMENT POLICY ON OVERTIME DETERMINATION

12A     DBKLG.K=(13)(AOR.K)
21A     DIFFR.K=(1/DBKLG.K)(BKLG.K-DBKLG.K)
58A     ADJT.K=TABHL(TADJ,DIFFR.K,-.30,.5,.1)
44A     BKCD.K=(DIFFR.K)(DBKLG.K)/ADJT.K
20A     NTSRC.K=NUTS.K/NTSD
13A     NUTS.K=(TWF.K)(PPM)(NCTS)
20A     RATIO.K=TTSRD.K/NTSRC.K
```

```
7A      TTSRD.K=BKCC.K+NTSRC.K
58A     PROD.K=TABHL(TRA,RATIO.K,.6,2.0,.2)
58A     TSD.K=TABHL(TIPT,PROD.K,.6,2.0,.2)
7A      PD.K=PDM+PDVT.K
58A     PDVT.K=TABHL(TPDV,PROD.K,.6,2,.2)

        QUALITY SECTOR

58A     QUAL.K=TABHL(TQ,PROD.K,.6,2.0,0.2)
7A      DEFPC.K=1-QUAL.K
12R     DSR.KL=(TSRI.K)(DEFPC.K)
20A     TSRI.K=UTS.K/TSC.K
12R     GSR.KL=(TSRI.K)(QUAL.K)
39R     DAR.KL=DELAY3(DSR.JK,ST)
39R     GAR.KL=DELAY3(GSR.JK,ST)
3L      SDAR.K=SDAR.J+(DT)(1/DSD)(DAR.JK-SDAR.J)
3L      SGAR.K=SGAR.J+(DT)(1/DSD)(GAR.JK-SGAR.J)
48A     RATDT.K=SDAR.K/(SDAR.K+SGAR.K)
58A     IQSE.K=TABHL(TIQ,RATDT.K,.05,.25,.05)

        SALES EFFORT SECTOR

7R      DNSE.KL=NSEPW+0
1L      ADSE.K=ADSE.J+(DT)(DNSE.JK+0)
1L      AASE.K=AASE.J+(DT)(ASE.JK+0)
21A     CORSE.K=(1/TASE)(ADSE.K-AASE.K)
51R     ASE.KL=CLIP(XX.K,YY.K,ZZ.K,.93)
7A      ZZ.K=1-RATDT.K
7A      XX.K=NSEPW+AAA.K
15A     YY.K=(NSEPW)(IQSE.K)+(AAA.K)(CORAQ.K)
51A     AAA.K=CLIP(.8,CORSE.K,CORSE.K,.8)
56A     CORAQ.K=TABHL(TCAQ,ZZ.K,.87,.93,.02)
3L      AVSE.K=AVSE.J+(DT)(1/DT)(ASE.JK-AVSE.J)

        INITIAL CONDITIONS

6N      TEST=0
6N      AOR=1000
6N      APFR=1000
6N      WIT=.2
6N      TWF=100
6N      UPB=4000
6N      UPR=5000
6N      UTS=4000
6N      BKLG=13000
6N      APSR=1000
6N      SDAR=50
6N      SGAR=950
6N      ADSE=0
6N      AASE=0
6N      AVSE=1

        CONSTANTS

C       PONC=1000
C       DRO=12
C       TAO=24
```

```
C        DAPFR=16
C        TFI*=.002/.004/.007/.013/.020
C        TFDW*=.02/.013/.007/.004/.002
C        DTW=9
C        PRM=10
C        RR=250
C        EDD=4
C        PDM=3
C        TPDV*=2.4/2.2/2.0/1.8/1.4/.85/.55/0
C        NTSD=4
C        TRA*=.65/.80/1/1.3/1.6/1.8/1.9/2
C        TBPT*=5.5/4.5/4.0/3.6/3.2/2.8/2.4/2.0
C        TQ*=.95/.95/.95/.93/.90/.86/.81/.75
C        TADJ*=10/9/8/7/6/3/2/1/1
C        ST=3
C        DSD=2
C        TCAD*=0/.2/.6/1.0
C        TIQ*=1/.87/.76/.7/.6
C        TT=4
C        TASE=12
C        NDTS=4
C        NSEPW=1

PLOT     TSR=T,PFR=F/OR=C,PO=P/ADJT=J/AVSE=V(.5,2)/PROD=*(C,2)/QUAL=Q(.5,1)
X1
PLOT     TWF=W/BKLG=K,DBKLG=D/UIE=1,UIP=2,UTS=3/RATIO=X/RATDT=Z
PLOT     DIFE=2/E=B/TSD=H/PD=U/ADSE=R/AASE=S/CORSE=M
SPEC     DT=1/LENGTH=300/PRTPER=6/PLTPER=2

N        EQUATION FOR    PO,    WH,   DSR,   GSR, FIWF, DIFE,    B,    E,    D,    C
N        EQUATION FOR     A,    WF,DEFPC, QUAL, PROD,RATIO,NTSRC, NUTS,TBSRD, BKCD
N        EQUATION FOR  ADJT,DIFFR,DBKLG, TSRI,  TSD
```

APPENDIX B

LIST OF VARIABLES AND PARAMETERS

APPENDIX B

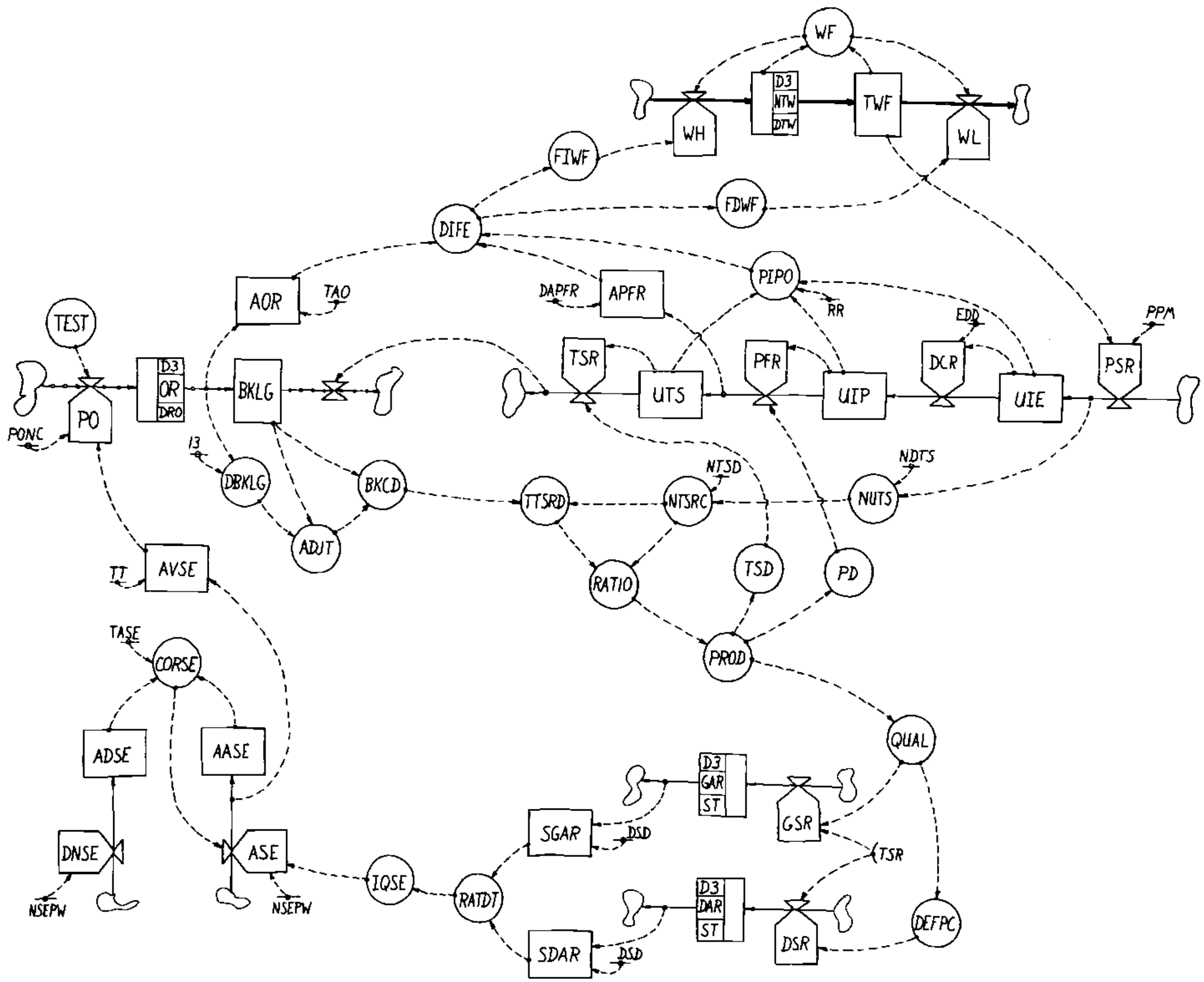
LISTING OF VARIABLES AND PARAMETERS

AASE - Accumulated Actual Selling Effort (normal units)
ADJT - Backlog Adjustment Time (wks)
ADSE - Accumulated Desired Selling Effort (normal units)
AOR - Average Orders Rate (orders/wk)
APFR - Average Production Finishing Rate (units/wk)
ASE - Actual Selling Effort (normal units/wk)
AVSE - Average Sales Effort (normal units/wk)
BKCD - Backlog Correction Desired (units/wk)
BKLG - Backlog (orders)
CORSE - Correction to Selling Effort (normal units/wk)
DAPFR - Delay to Average Production Finishing Rate (wks)
DAR - Defective Arrival Rate (units/wk)
DBKLG - Desired Backlog (units)
DCR - Design Completion Rate (units/wk)
DEFPC - Defective Percentage (dimensionless)
DIFE - Difference Indicated for Expansion (units/wk)
DIFFR - Difference Ratio (dimensionless)
DNSE - Desired Normal Selling Effort per Week
DRO - Delay to Receive Orders (wks)
DSD - Delay to Smooth Shipment Quality
DSR - Defective Shipping Rate (units/wk)
DTW - Delay to Train Workers (wks)
EDD - Engineering Design Delay (wks)
FDWF - Fractional Decrease in Work Force (1/wk)
FIWF - Fractional Increase in Work Force (1/wk)
GAR - Good Arrival Rate (units/wk)
GSR - Good Shipping Rate (units/wk)
IQSE - Impact of Quality on Selling Effort (dimensionless)
NDTS - Normal Desired Testing and Shipping Rate
NSEPW - Normal Sales Effort Per Week
NTSRC - Normal Testing and Shipping Rate Capability (units/wk)
NTW - Newly Trained Workers (men/wk)
NUTS - Normal Units in Testing and Shipping (units)
OR - Order Rate (orders/wk)
PD - Production Delay (wks)
PDM - Production Delay Minimum (wks)
PDVT - Production Delay Variable Time (wks)
PFR - Production Finishing Rate (units/wk)
PO - Prospective Orders (orders/wk)
PONC - Prospective Orders Normal Constant
PPM - Productivity per Man (units/wk/man)
PROD - Overtime to Increase Productivity (dimensionless)
PSR - Production Starting Rate (units/wk)

QUA1 - Quality (dimensionless)
RATDT - Ratio of Defective to Total (dimensionless)
RATIO - Ratio of TTSRD to NTSRC (dimensionless)
RR - Pipeline Adjustment Time (wks)
SDAR - Smoothed Defective Arrival Rate
SGAR - Smoothed Good Arrival Rate
ST - Shipping Time (wks)
TADJ - Table for Backlog Adjustment Time
TAO - Time to Average Orders (wks)
TASE - Time to Average Selling Effort (wks)
TEST - Test Input (orders/wk)
TFDW - Table for Fractional Decrease in Work Force
TFI - Table for Fractional Increase in Work Force
TIPT - Table for Impact of Productivity on Testing and Shipping Delay
TIQ - Table of Impact of Quality on Selling Effort
TPDV - Table of Productivity Delay Minimum
TQ - Table of Quality from Productivity
TRA - Table for Determining Productivity
TSD - Testing and Shipping Delay (wks)
TSR - Testing and Shipping Rate (units/wk)
TSRI - Testing and Shipping Rate Indicated (units/wk)
TT - Time to Average Actual Selling Effort (wks)
TTSRD - Total Testing and Shipping Rate Desired (units/wk)
TWF - Total Work Force (men)
UIE - Units in Engineering (units)
UIP - Units in Production (units)
UTS - Units in Testing and Shipping (units)
WF - Work Force (men)
WH - Workers Hired (men/wk)
WIF - Workers in Training
WL - Workers Leaving (men/wk)

APPENDIX C

COMPOSITE FLOW DIAGRAM


WF
D3
NTW
DTW
TWF
WH
WL
FIWF
FDWF
DIFE
PIPO
AOR
TAO
DAPFR
APFR
RR
EDD
PPM
TEST
D3
OR
DRO
BKLG
PO
PONC
TSR
UTS
PFR
UIP
DCR
UIE
PSR
I3
DBKLG
BKCD
TTSRD
NTSD
NTSRC
NDTS
NUTS
ADJT
TT
AVSE
RATIO
TSD
PD
TASE
CORSE
PROD
QUAL
ADSE
AASE
D3
GAR
ST
GSR
SGAR
DSD
DNSE
ASE
IQSE
RATDT
TSR
NSEPW
NSEPW
D3
DAR
ST
DSR
DEFPC
SDAR
DSD

BIBLIOGRAPHY

References Cited

1. Green, Paul E. and Halbert, M. H. and Robinson, P.J., "A Behavioral Experiment in Sales Effort Allocation," Journal of Marketing Research, Vol. III (August 1966), pp. 261-268.

2. Forrester, Jay W., Industrial Dynamics, The M.I.T. Press, Cambridge, Massachusetts, 1965.

3. Ibid, p. 13

4. Mandel, Milton M., "A Company Guide to the Selection of Salesmen," American Management Association, Research Report #24.

5. Nord, Ole C., "The Problem of Workload Fluctuation at the Precision Company," Industrial Dynamics Research Memo, D-588-2, (an unpublished memo), Oct. 1963.

6. Roberts, Edward B., "Industrial Dynamics and the Design of Management Control Systems," Management Technology, Vol. III (December 1963), pp. 100-118.

7. Schussel, George, "Sales Forecasting with the Aid of a Human Behavior Simulator," Management Science, Vol. 13 (June 1967), pp. B-593-601.

8. Swanson, Carl V., "Some Properties of Feedback Systems as a Guide to the Analysis of Complex Simulation Models," Proceedings of the Department of Defense Logistics Research Conference, Worrenton, Virginia, May 1965. pp. 7-8.

9. Thompson, William W., Jr., and McNeal, J.U., "Sales Planning and Control Using Absorbing Markov Chains," Journal of Marketing Research, Vol. IV (February 1967), pp. 62-66.

10. Wilson, H.S. "A Study of the Influence of Level of Performance on Work Time Distributions," M.S. Thesis, Georgia Institute of Technology, 1955.

References Not Cited

11. Pugh, Alexander L. III, DYNAMO User's Manual, The M.I.T. Press, Cambridge, Massachusetts, 1963.